ClimateAction Planning San Luis Obispo, CA 1/31/2013

Planning for climate change in California

substantial shifts on top of already high climate variability

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USGS Water Resources Discipline

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much support from Mary Tyree, Guido Franco and other colleagues

Sponsors:

California Energy Commission

NOAA RISA program

California DWR, DOE, NSF

in comparison to 4th IPCC (CMIP3) GCMs :

CMIP5 models provide:

more simulations

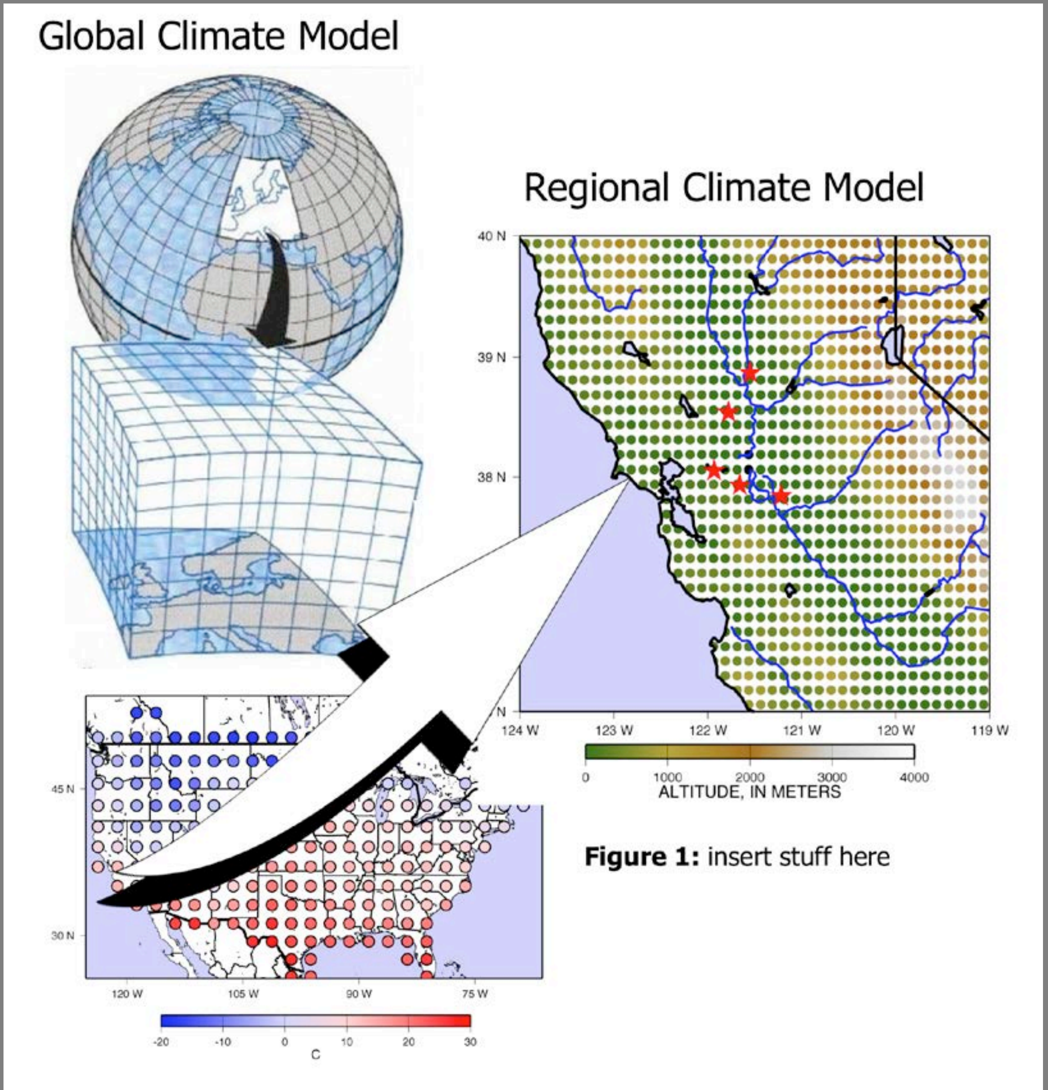
higher spatial resolution

more developed process representation

daily output is more available

in general, regional climate changes are similar, but not identical to previous generation CMIP3 model results

Global to regional downscaling



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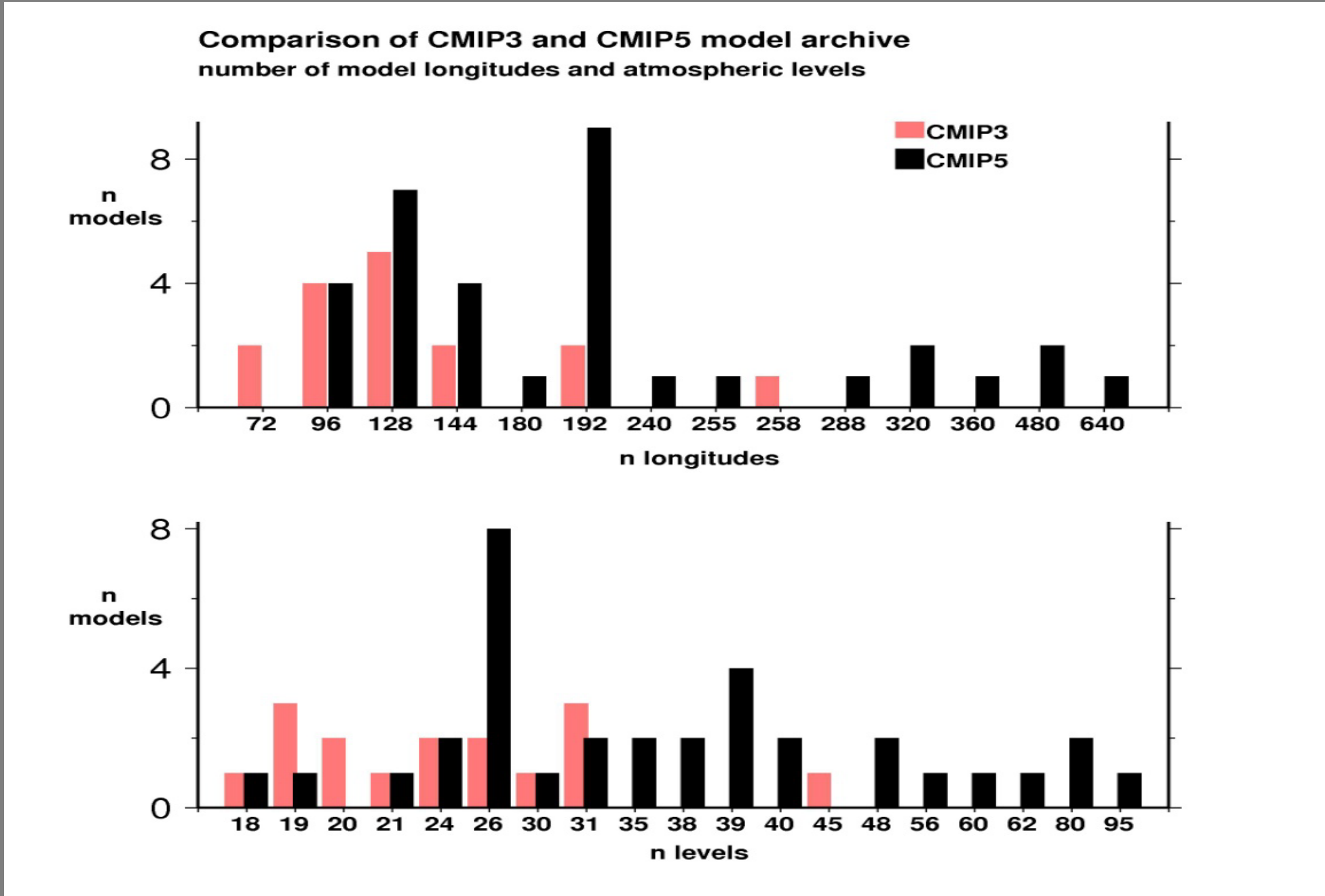
GCMs ~150km downscaled to Regional models ~ 12km

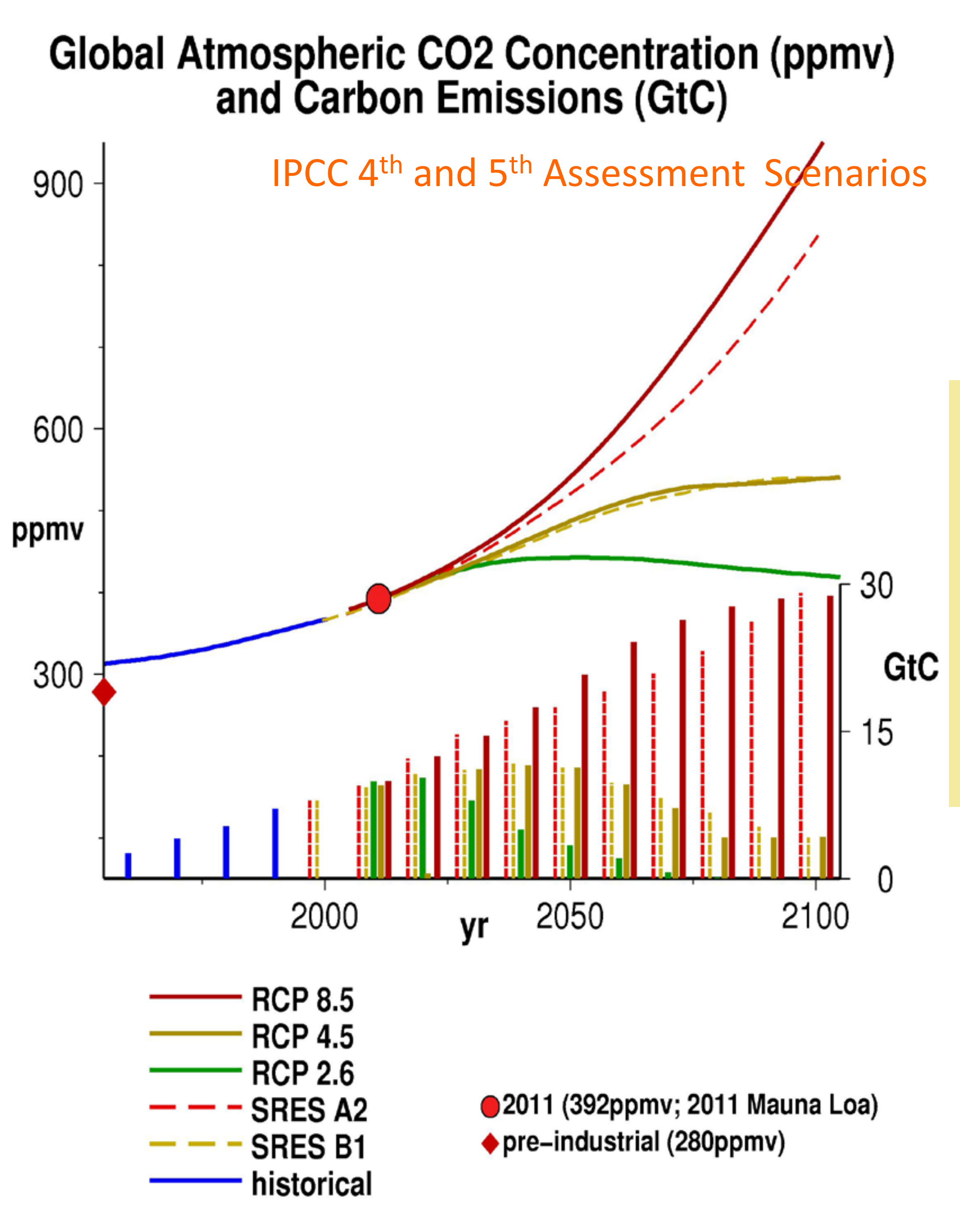
Many simulations IPCC AR4 and IPCC AR5 have been downscaled using statistical methods



CMIP3 models:
BCCR–BCM2.0, CCSM3, CNRM–CM3, CSIRO–Mk3.0, ECHAM5/MPI–OM, ECHO–G, GFDL–CM2.0, GFDL–CM2.1, INM–CM3.0, IPSL–CM4, MIROC3.2(medres), MRI–CGCM2.3.2, PCM, UKMO–HadCM3, GISS–ER, CGCM3.1(T47)

CMIP5 models:
ACCESS1.0, BCC–CSM1.1, CanESM2, CanCM4, CCSM4, CESM1(BGC), CESM1(CAM5), CESM1(CHEM), CESM1(WACCM), CMCC–CESM, CMCC–CM, CMCC–CM5, CSIRO–Mk3.6.0, EC–EARTH, FGOALS–G2, FGOALS–S2, GFDL–CM3, GFDL–ESM2G, GFDL–ESM2M, GISS–E2–R, HadCM3, HadGEM2–CC, HadGEM2–ES, IPSL–CM5A–LR, IPSL–CM5A–MR, MIROC–ESM, MIROC–ESM–CHEM, MIROC4h, MIROC5, MPI–ESM–LR, MRI–CGCM3, NorESM1–M, INM–CM4, CNRM–CM5

Increased resolution
CMIP5 vs CMIP3 GCMs



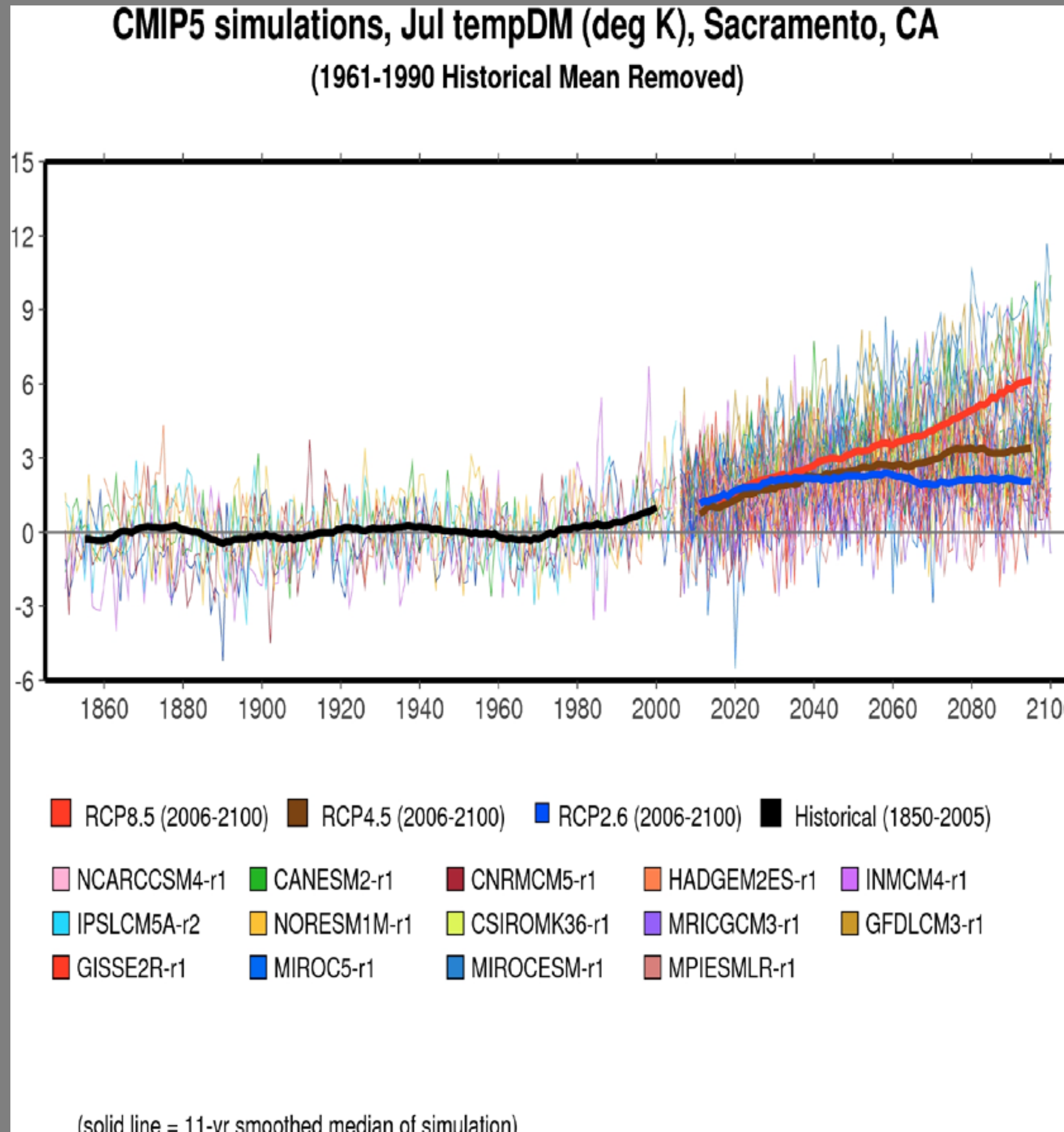
different greenhouse gas emissions trajectories would have enormous impacts on climate in future decades

Uncertainty is substantial in climate projections

Temperature Change

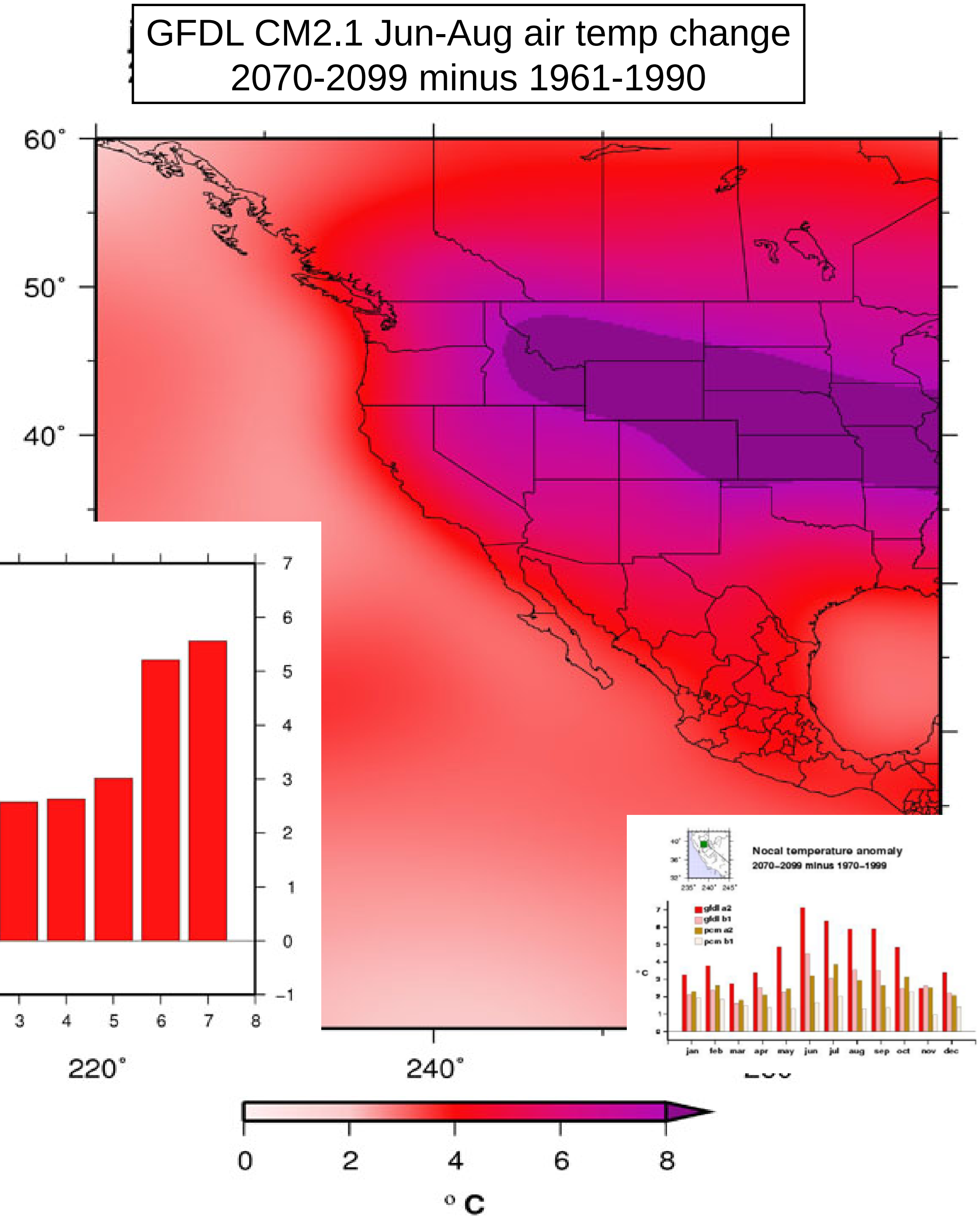
14 GCMs X 3 RCP emissions Scenarios

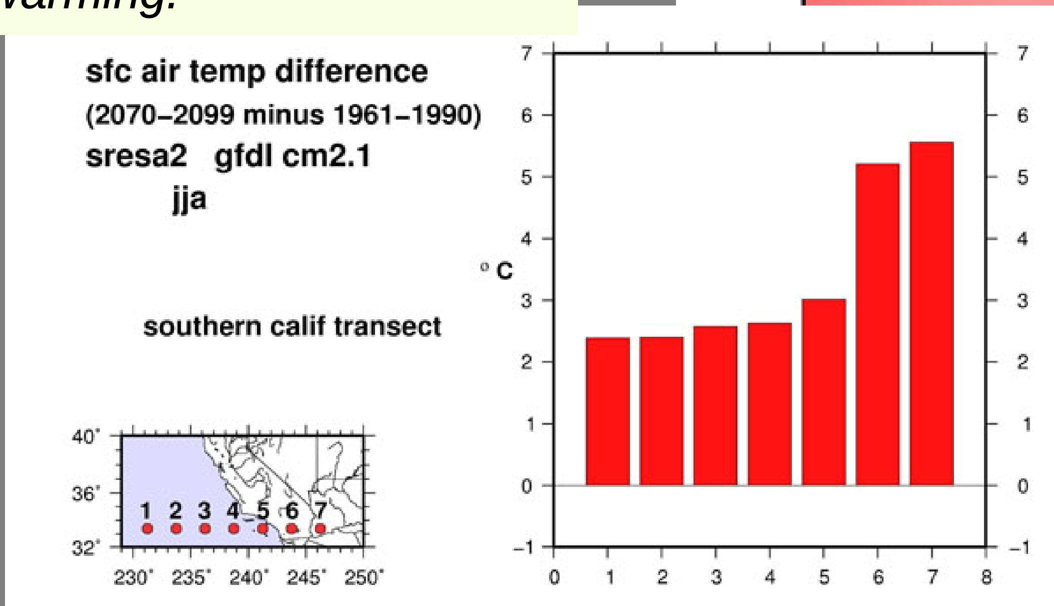
IPCC 5th Assessment (CMIP5) models



Climate models project ocean warming by end of century of 1.5-2.C greater warming on land than oceans would amplify thermal gradient across California coast-interior

Some models produce accentuated summer land warming.



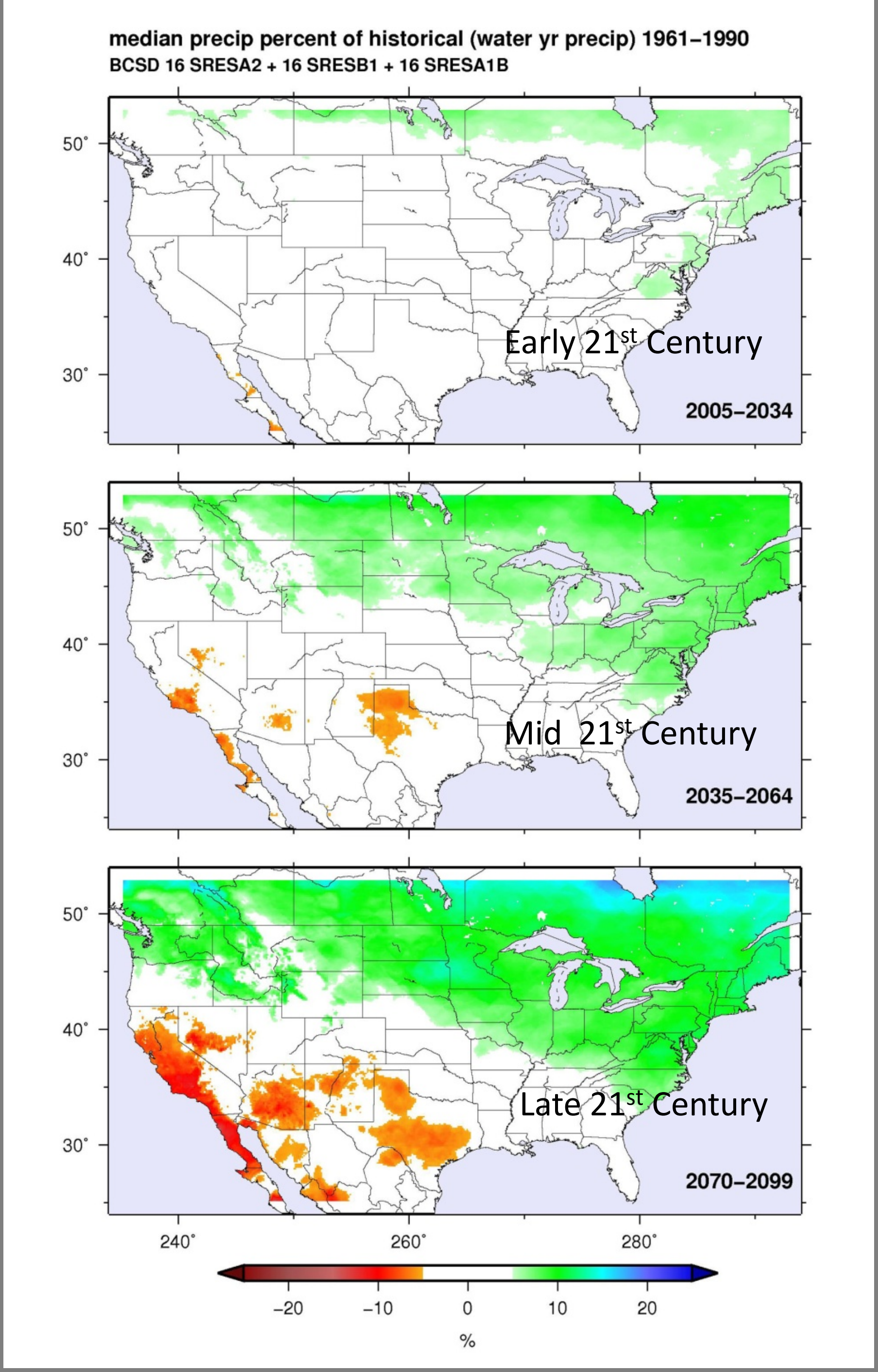


Projected Precipitation Change

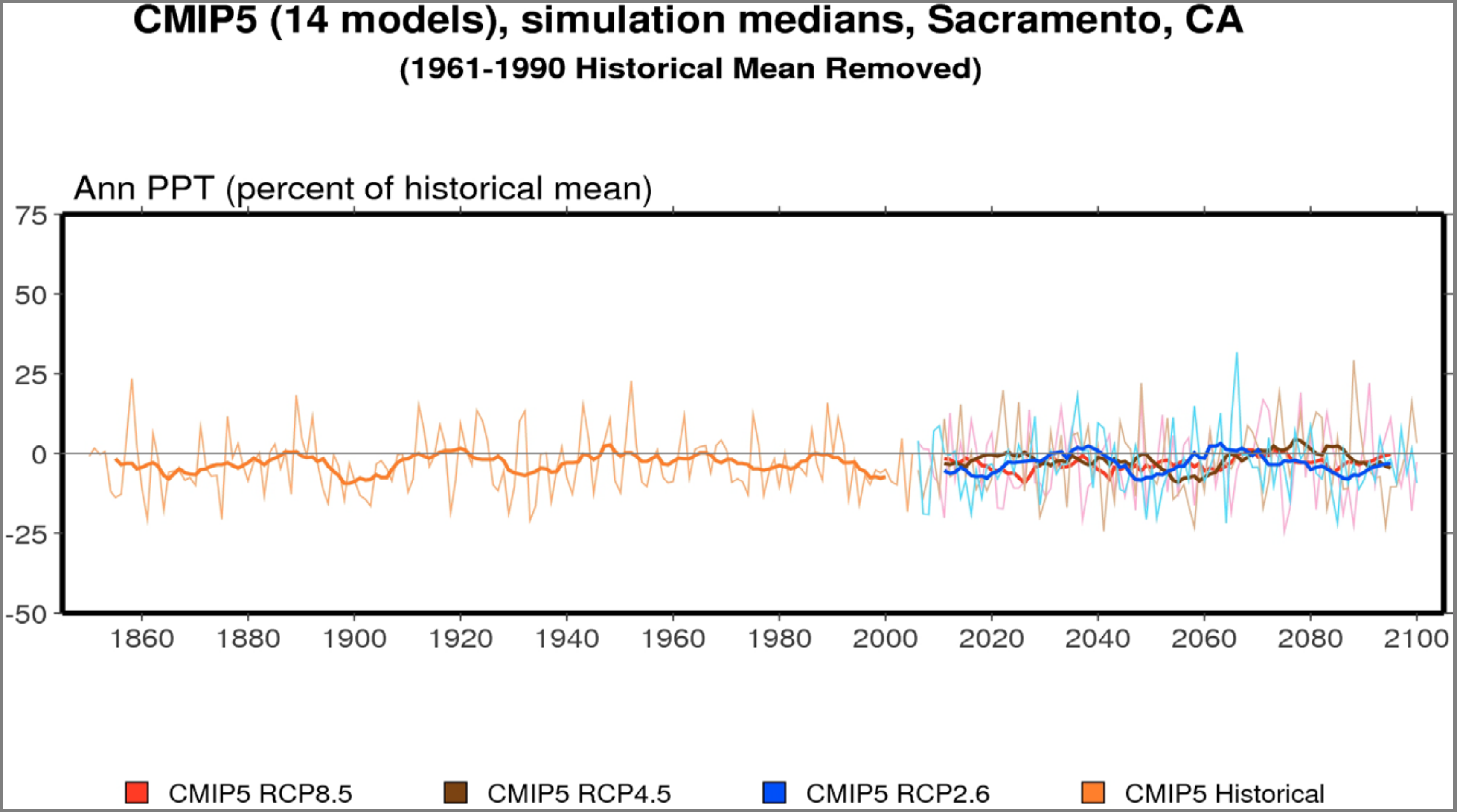
Incrementally drier Southwest,
especially Southern California
develops over the 21st Century.

Drying becomes greater
as climate becomes warmer

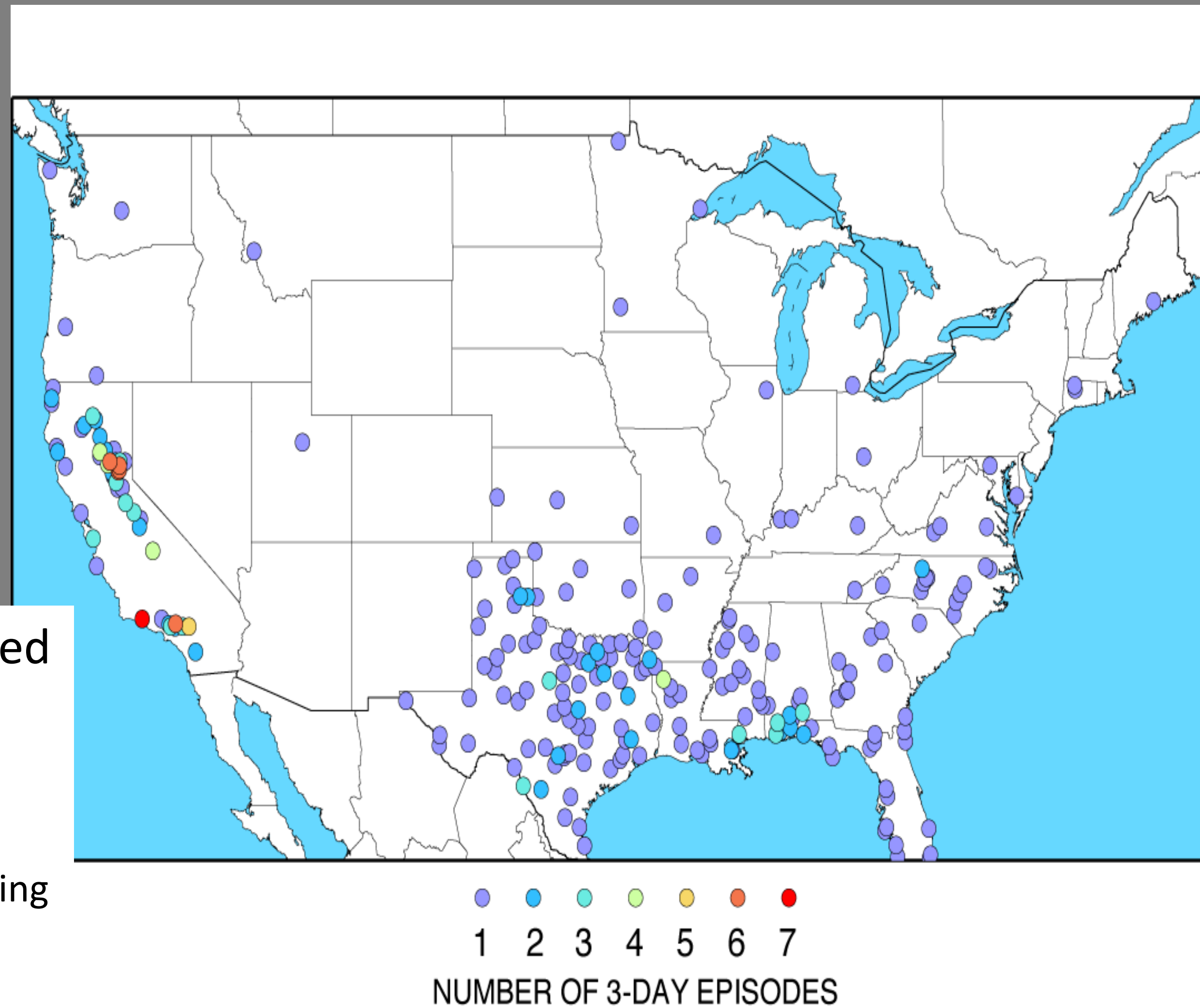
from 48 climate model simulations
downscaled to 12km using BCSD



Precipitation Change 14 GCMs X 3 new Emissions Scenarios IPCC 5th Assessment models



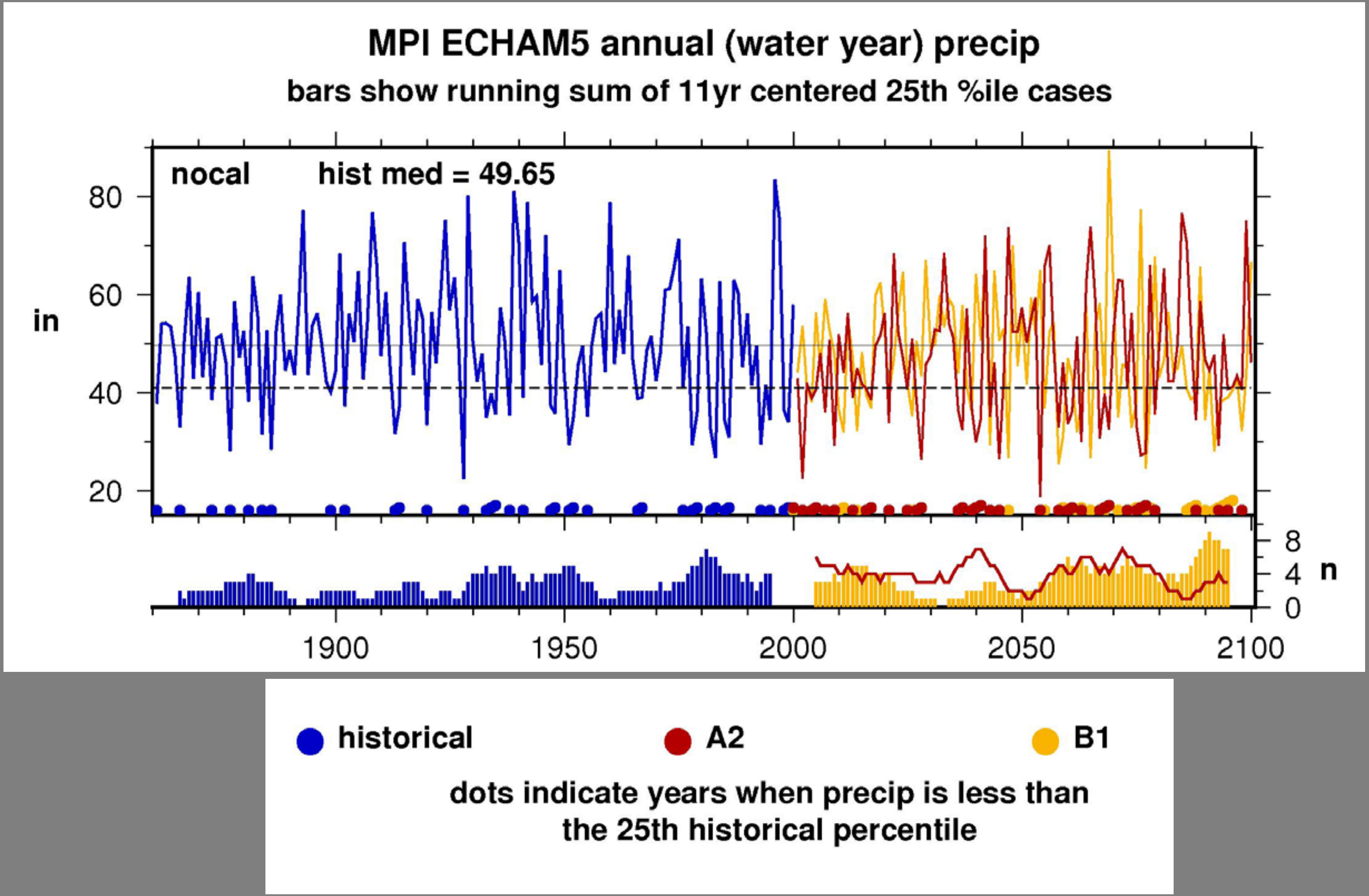
High variability of weather and short term climate will continue



Stations that have recorded the highest 3-day precipitation amounts

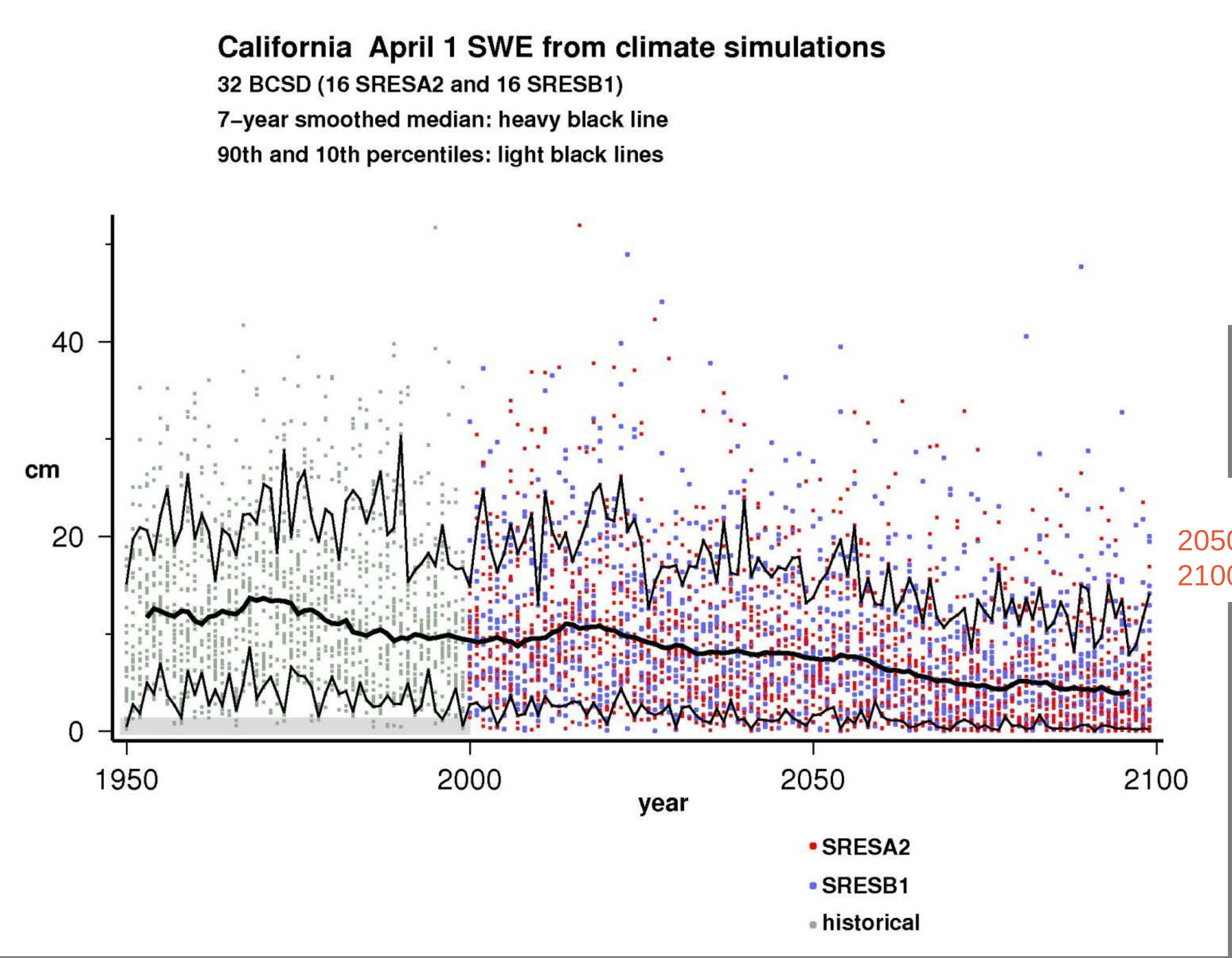
Numbers of non-overlapping 3-day precipitation totals at COOP weather stations that exceeded 40 cm (15.75") from 1950-2008.

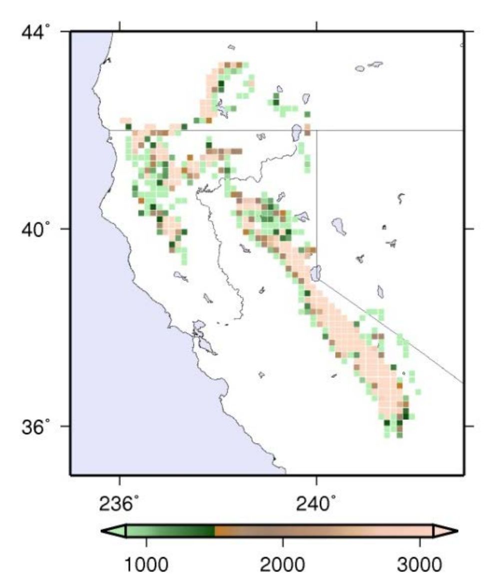
Scoping drought occurrence in GCM simulations
example from CMIP3 era



but change in snow water projected for Sierra Nevada+ is substantial

16 GCMs, A2 and B1 emissions scenarios

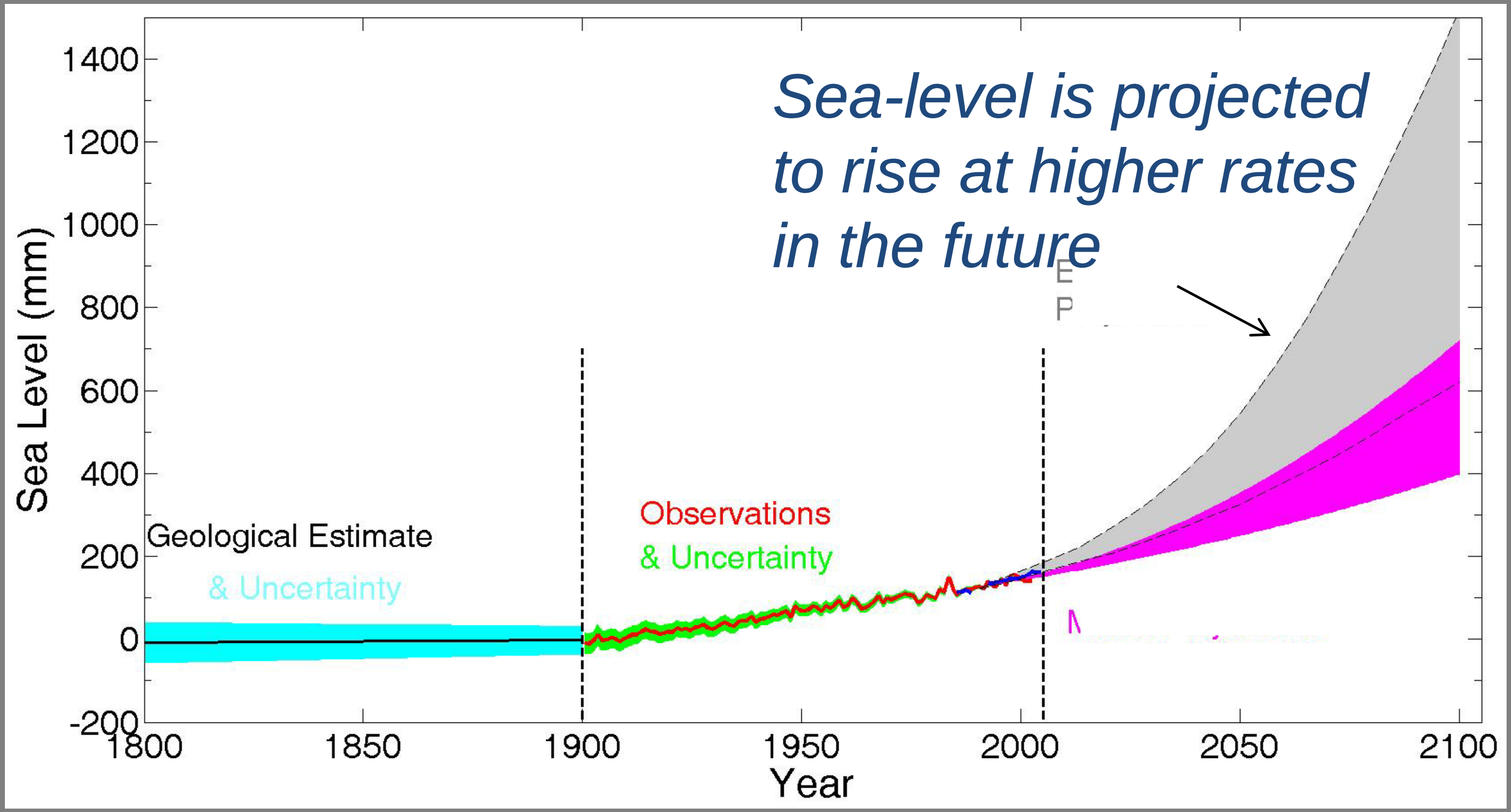




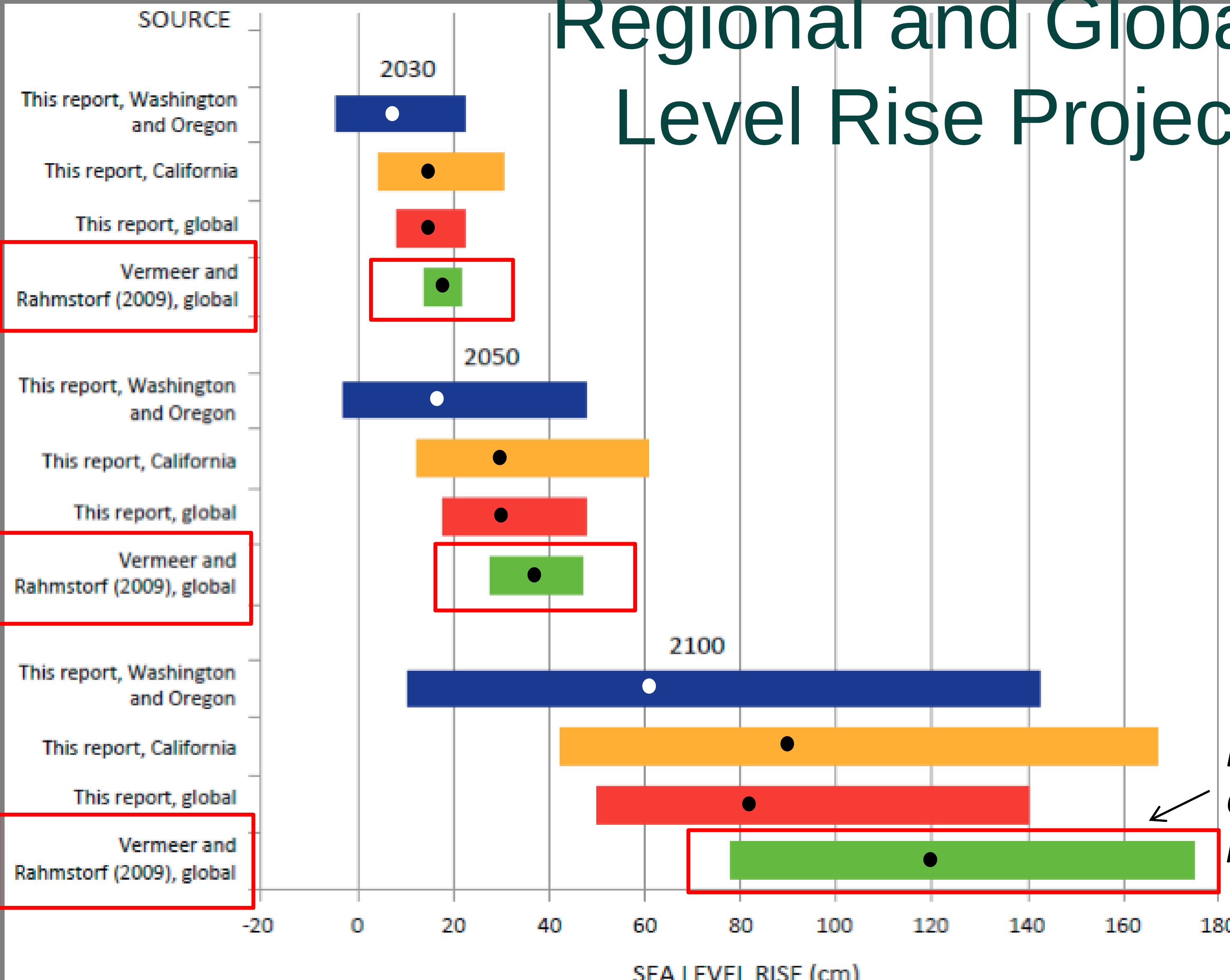
declining Apr 1 SWE:
2050 median SWE ~ 2/3 historical median
2100 median SWE ~ 1/3 historical median

Global sea-level is rising primarily because land ice is melting and ocean water expands as it warms.

1.7 mm per year over 20th century (from tide gages)
3.1 mm per year since 1993 (from satellites & tide gages)



Regional and Global Sea-Level Rise Projections

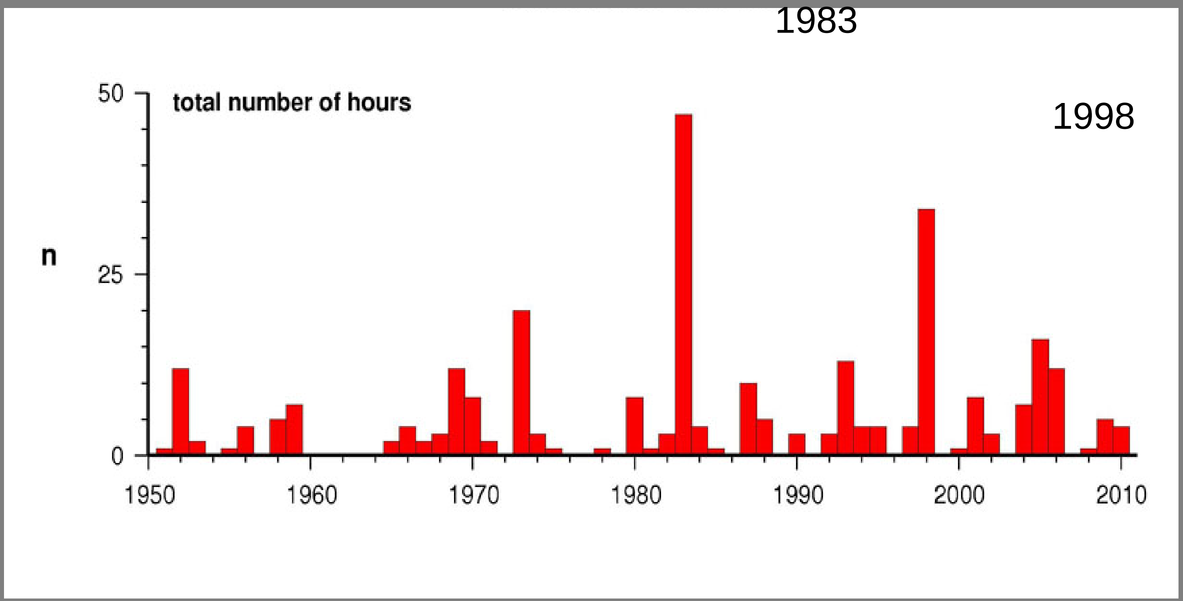


Being used by California for interim planning during high sea levels, the sea is often *not* quiescent

January 1983 Monterey Bay, California

Extreme sea level occurrences San Francisco

observed at or above 99.99% historical hourly threshold 1.41m above mean

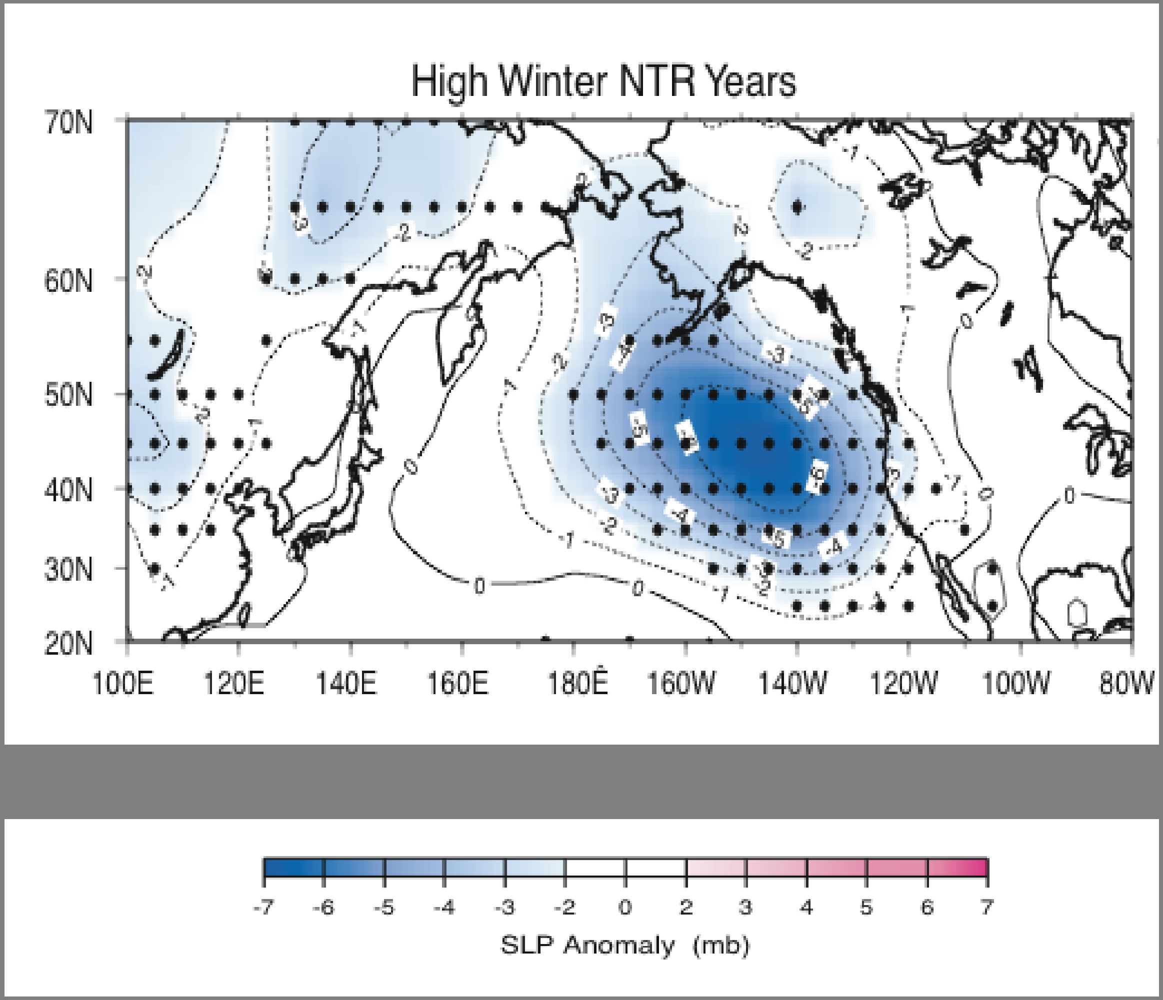


highest California
sea levels have mainly
occurred in
just a few years, esp
large El Ninos
(1983 and 1998)

from hourly sea level record
at Ft Point, mouth of San
Francisco Bay

Large atmospheric fingerprint of highest sea levels

composite monthly anomalous atmospheric circulation patterns during winters with very high non-tide (anomalous) sea level heights



Intensified, southerly-displaced low pressure during the 10 highest non-tide winter extremes since 1900

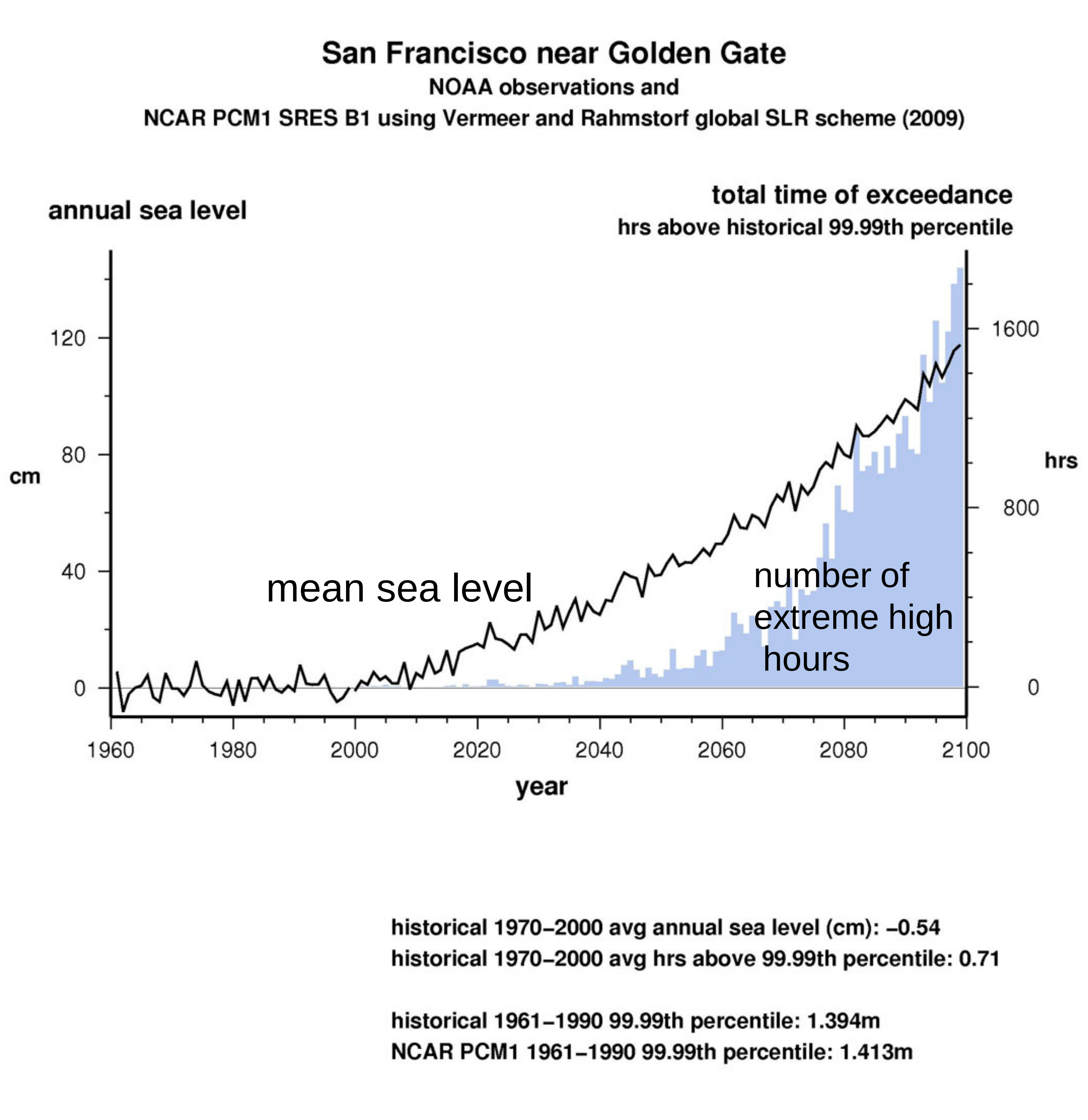
The footprint of low barometric pressure and high winds during These winters is often quite large, creating Simultaneous sea level disturbances over the California coast, Bay And Delta

The *pace* of climate change is projected to be rapid

INCREASING SEA LEVEL EXTREMES

As mean sea level rises the frequency and magnitude of extremes would increase markedly. Under plausible rates of sea level rise, an event which in present day occurs less than once per year occurs scores of times per year by mid 21st Century and becomes commonplace by end of 21st Century.

Importantly the duration of extremes becomes longer, so exposure to waves is considerably greater.



Future Storminess

- No consensus whether the number and severity of storms in the northeast Pacific will change
- Some models predict a northward shift in North Pacific storm tracks
  - If so, winter storm impacts would decrease in southern California and might increase in Oregon and Washington
- Some observational studies report that largest waves are getting higher and winds are getting stronger
  - If so, the frequency and magnitude of extremely high coastal wave events will likely increase
- Observational records are not long enough to confirm whether these are long-term trends

for CASCADE2, we are preparing to deliver:

1) an ensemble (10+ GCMs, 2+ emissions scenarios) of downscaled simulations and sea level scenarios

2) within that ensemble, an identified subset of simulations having strong hydrologic extremes (drought and flood) for the CASCADE2 group to investigate.

Key Issues

Global Climate Projection Uncertainty

- GHG/Land Use Response over multi-decades
- Natural Variation, including multi-decadal and event scale processes
- Disposition of winter storms (track and intensity) is problematic

Downscaling

- Observational data to validate, train, monitor is crucial but sparse
- Projections in high gradient climate regions are very fuzzy.
- Dynamical downscaling methods are computationally expensive, still developing

Sea Level Rise

- Global sea level rise projections are greatly uncertain
- Pacific basin change has strong affect of natural interannual-interdecadal variation
- Regional influences also play a role

Extreme Events

- Prolonged drought not well represented in GCMs
- Large floods only grossly replicated by GMCs and downscaling

Land Use Change

- not well represented in regional models and surely not in global models

Water Management

- crudely represented in regional models

global model to regional model downscaling

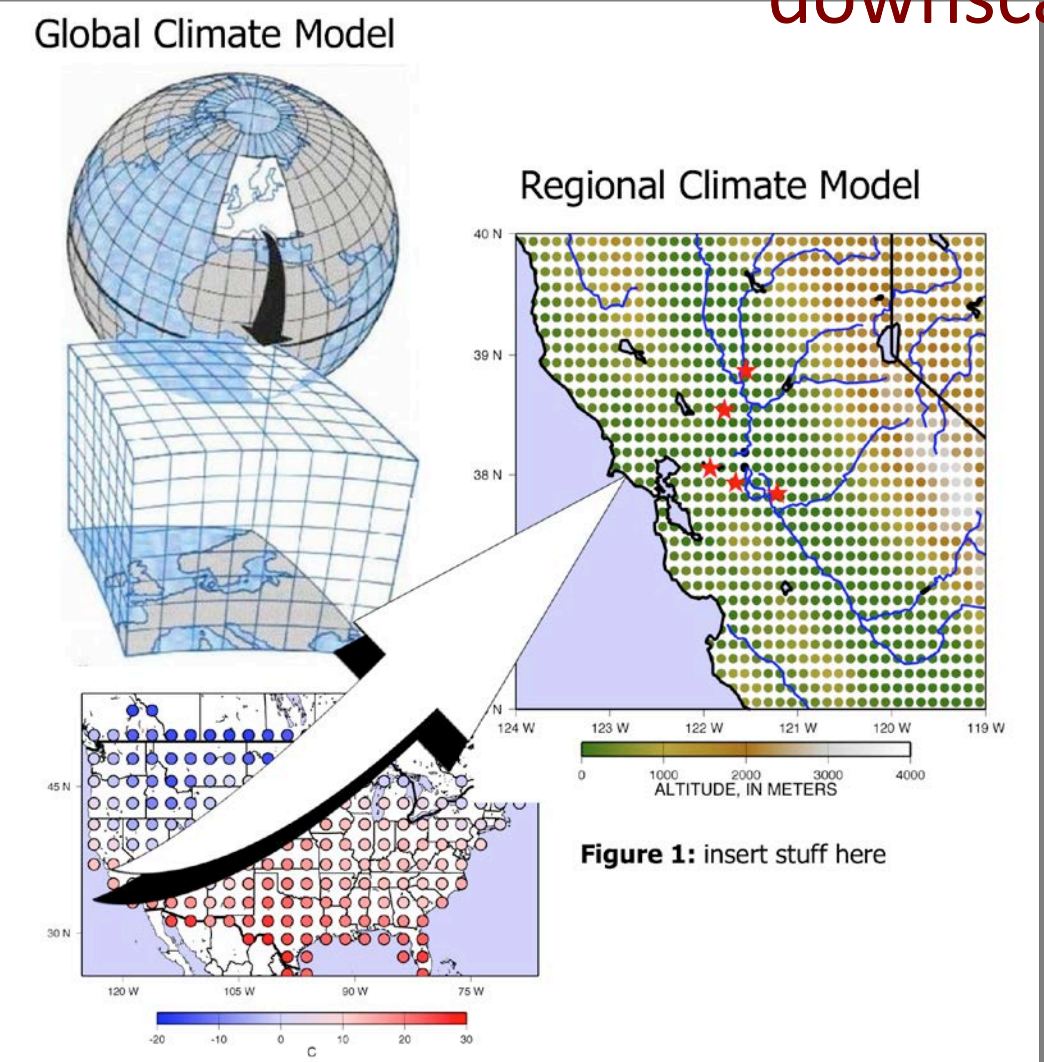
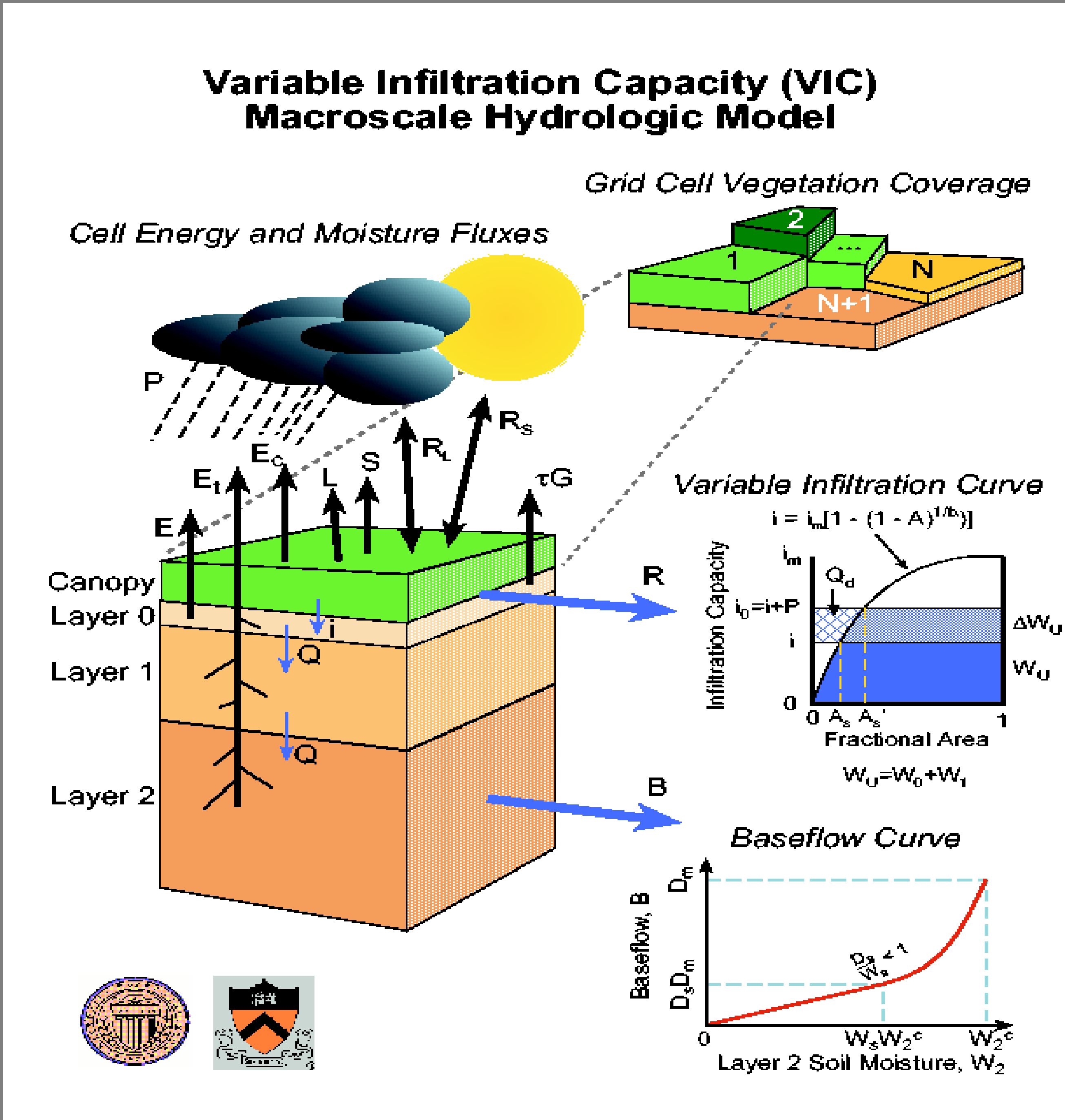


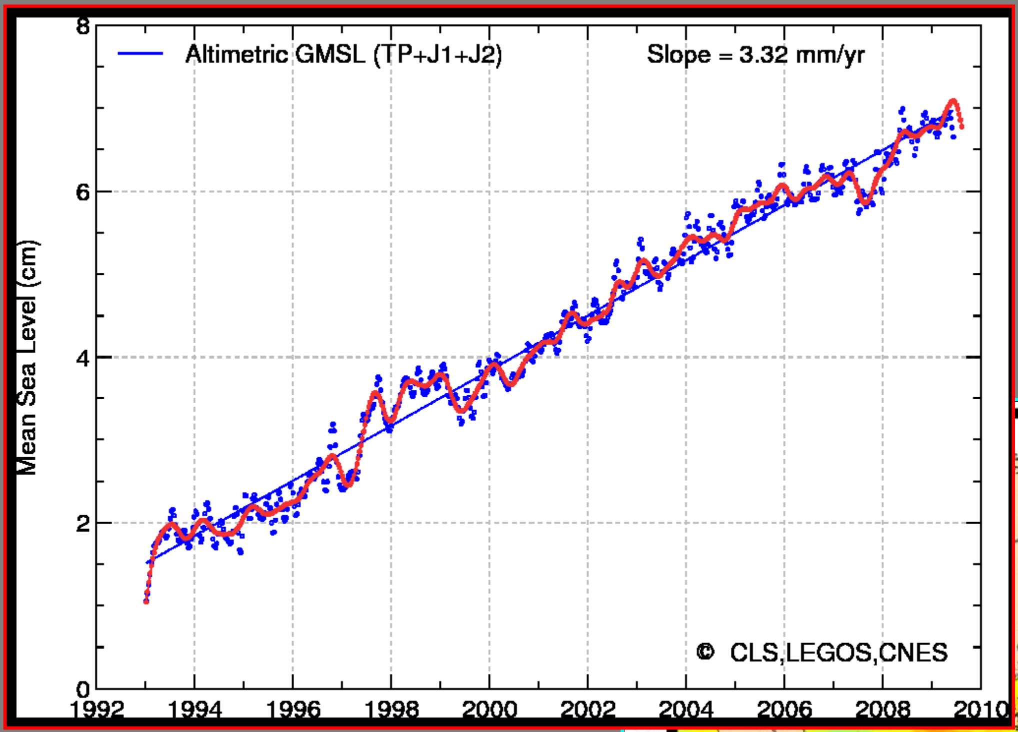
Figure 1: insert stuff here

GCMs ~150km downscaled to Regional models ~ 12km

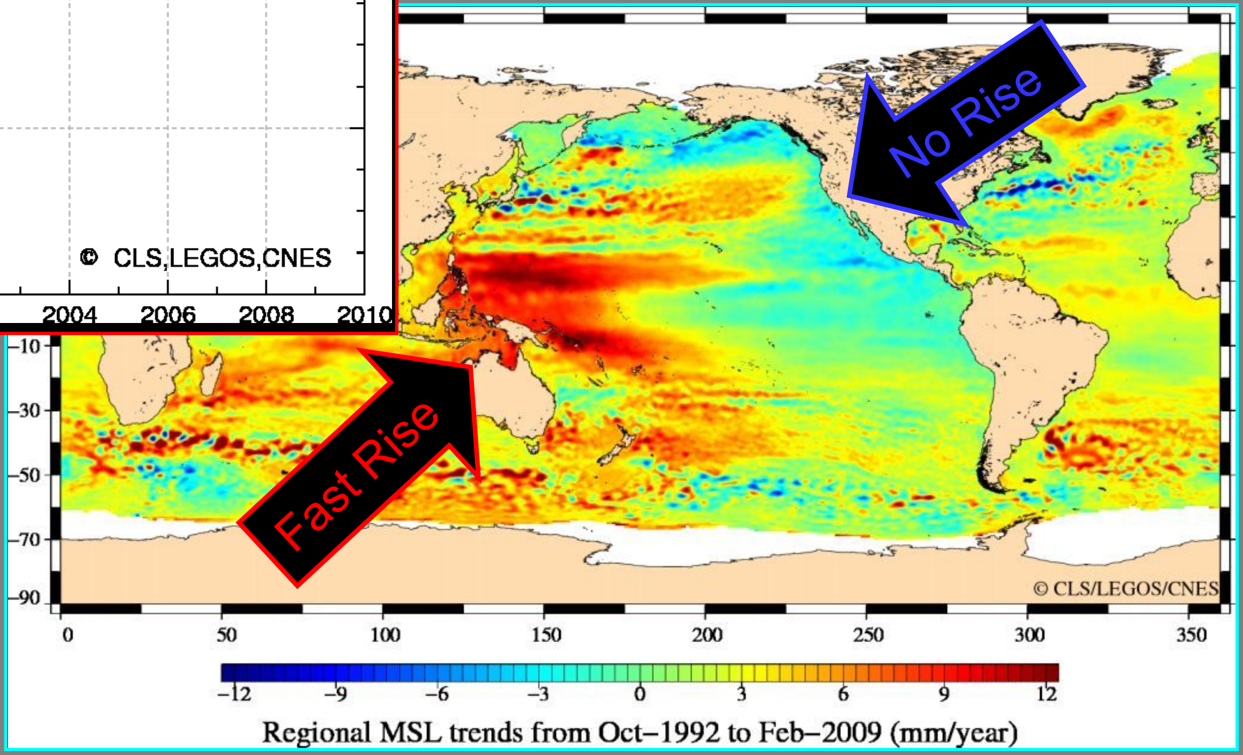


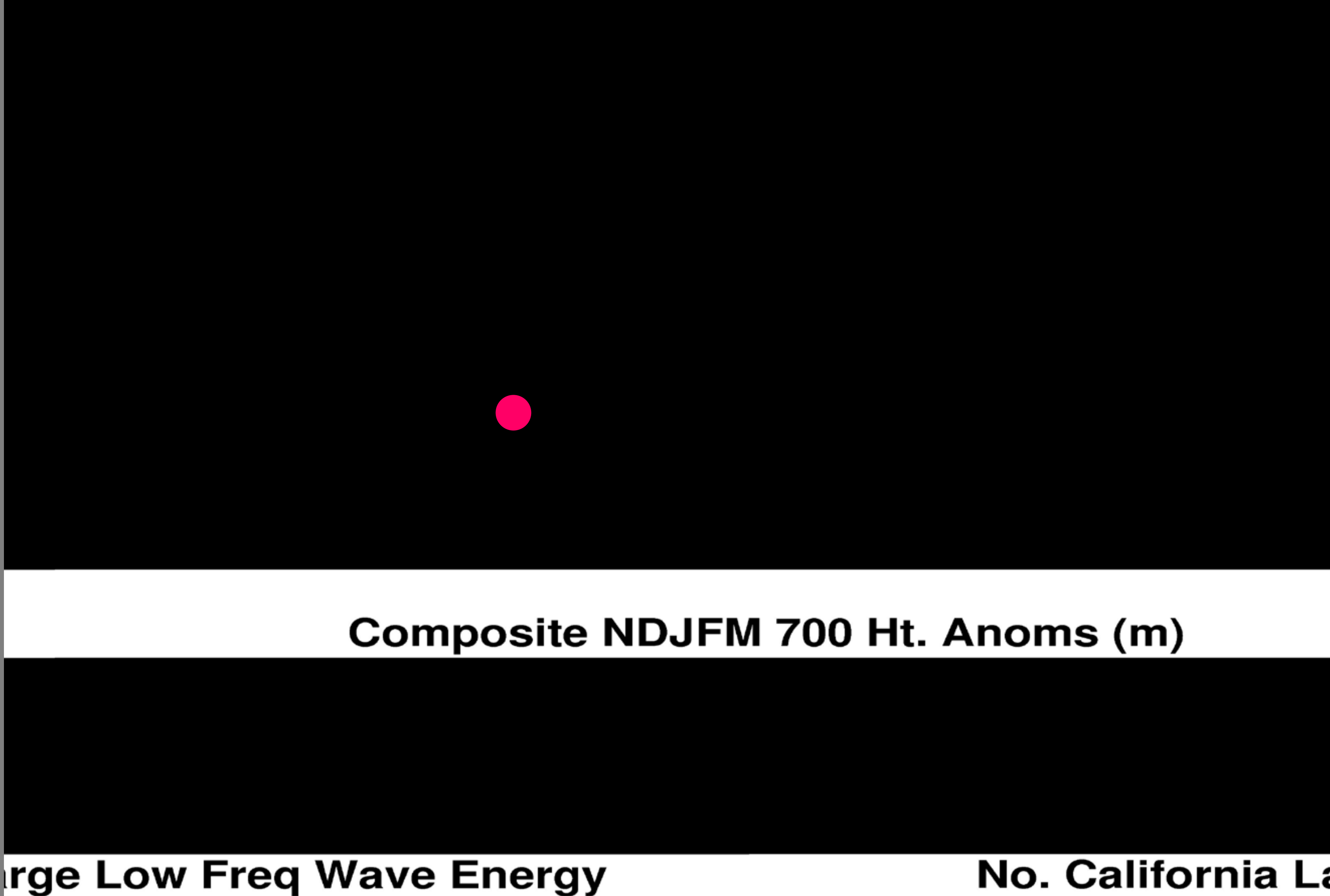
To estimate
water balance,
including
snow water equivalent
we use VIC,
a land surface
hydrologic
accounting
model, and
drive it with
precipitation,
temperature
and winds
over the western
United States

The Satellite Data 1992-2009



Global MSL not evenly distributed



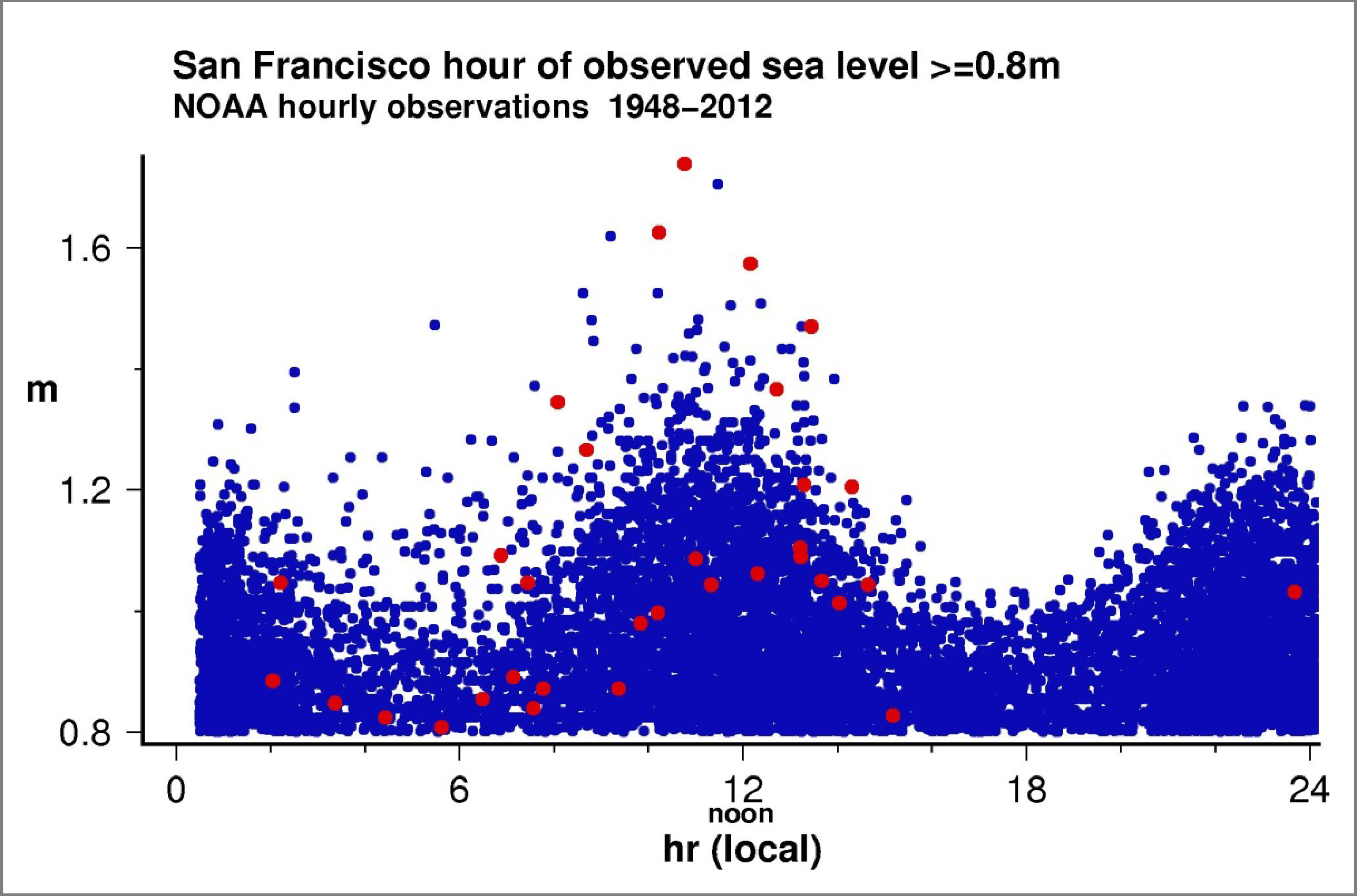


Atmospheric Circulation during large low frequency wave episodes

Bromirski et al 2005

this pattern produces long fetch, high

Along California coast, because of tide phases, highest Sea occur preferentially during narow windows of the day



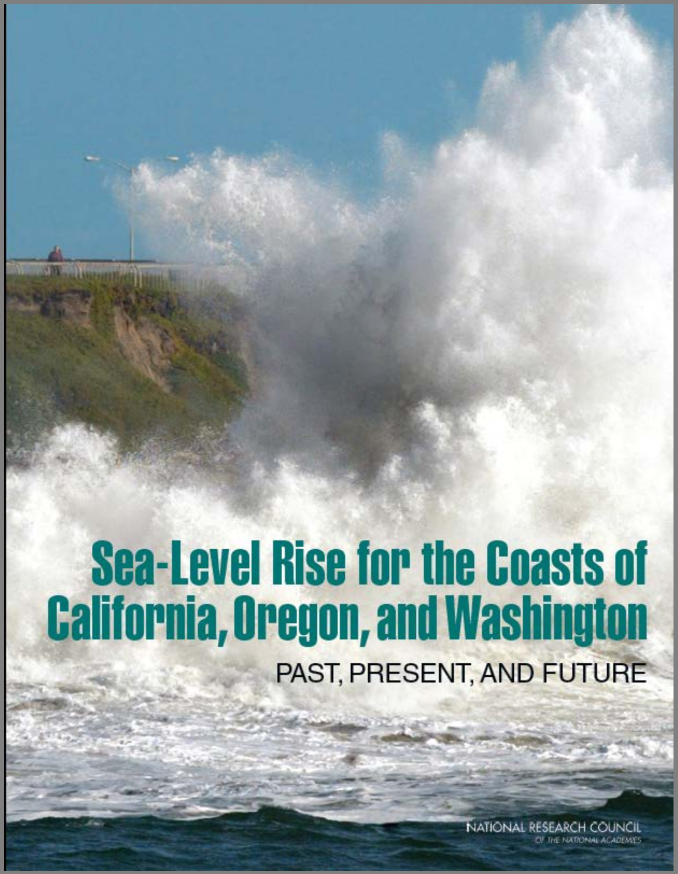
Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future—NRC Committee findings

from a presentation by

Dr. Robert A. Dalrymple,

Chair, NRC West Coast SLR Committee

Johns Hopkins University



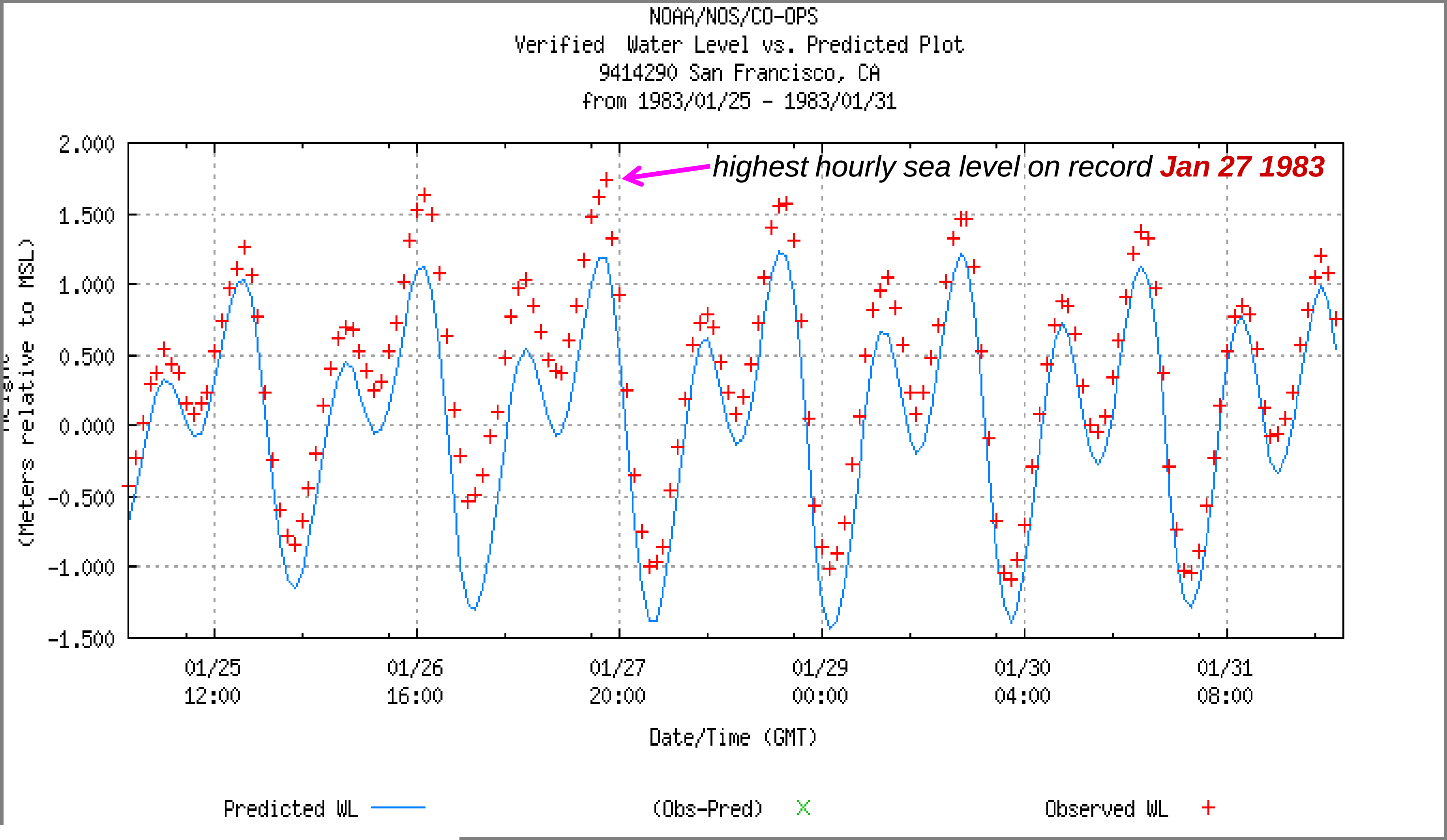
Study Origin

- 2008 California Executive Order
  - Directed state agencies to plan for sea-level rise and coastal impacts
  - Asked the National Research Council to assess sea-level rise
- The states of Oregon and Washington, NOAA, USACE, and USGS joined California in sponsoring this NRC study

Study Scope

- Task 1: Global Sea-Level Rise
- Task 2: Sea-Level Rise in CA, OR, and WA
  - 2 a Storminess Changes
  - 2 b,c Shoreline Responses

Greatest problems: large storm + high tide



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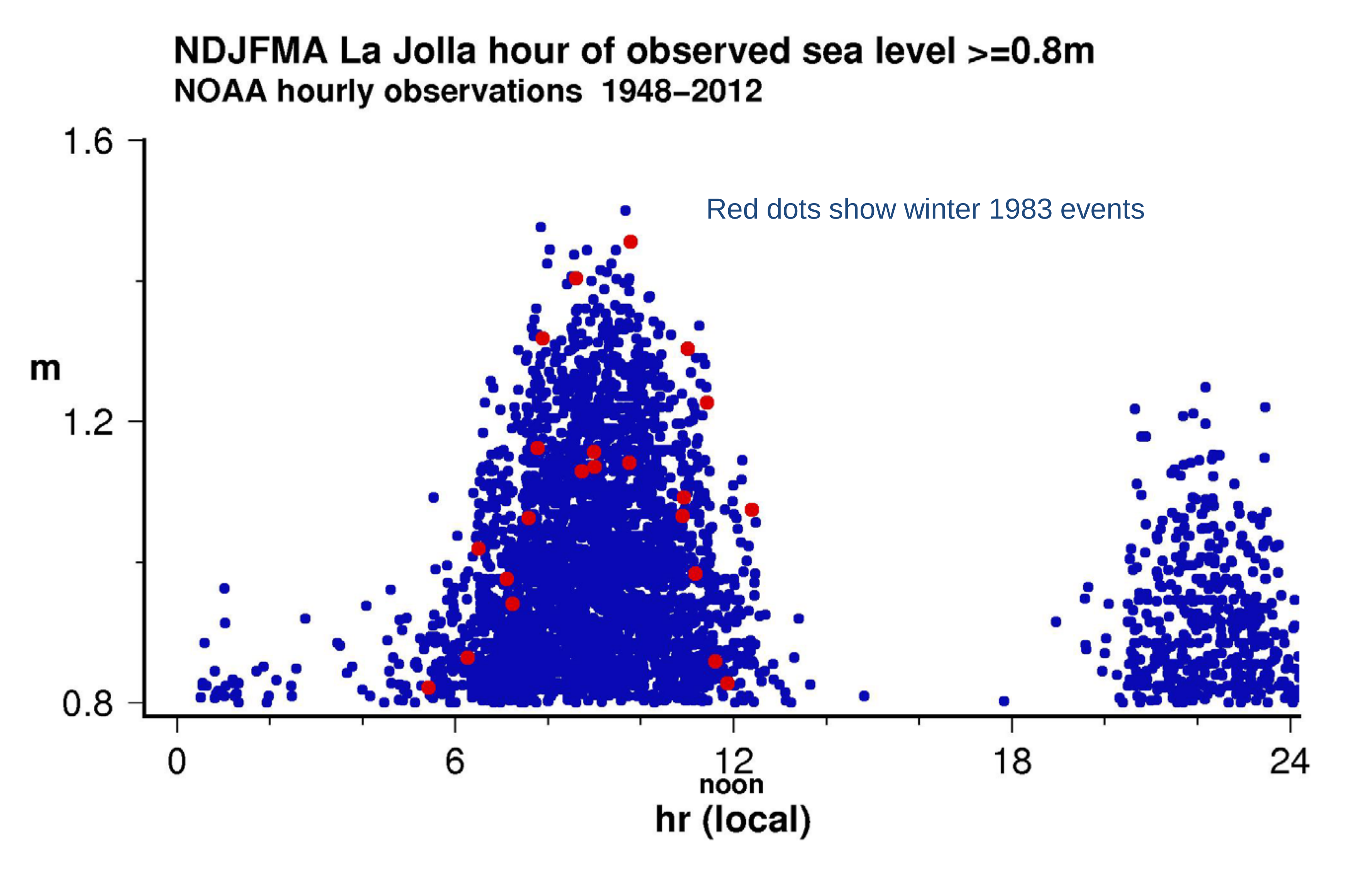
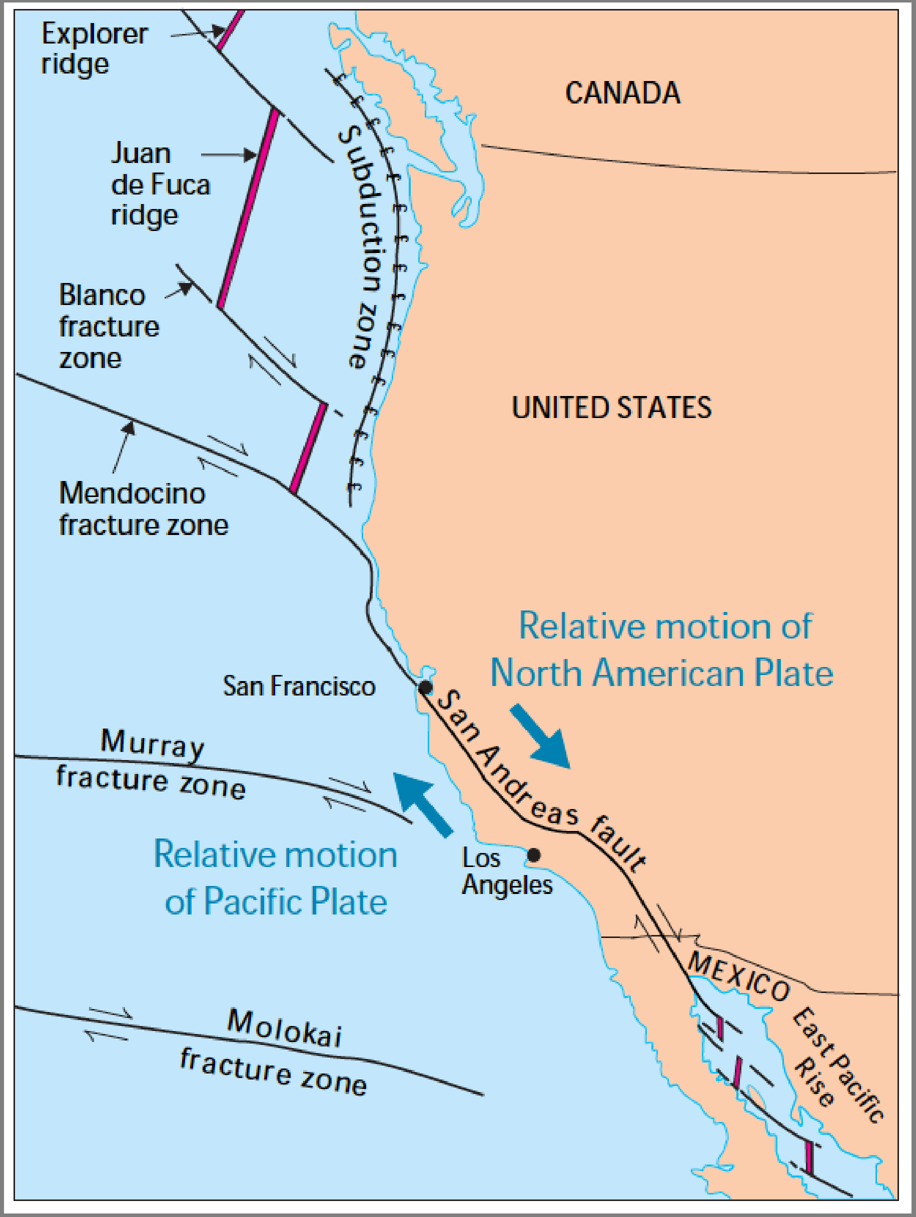


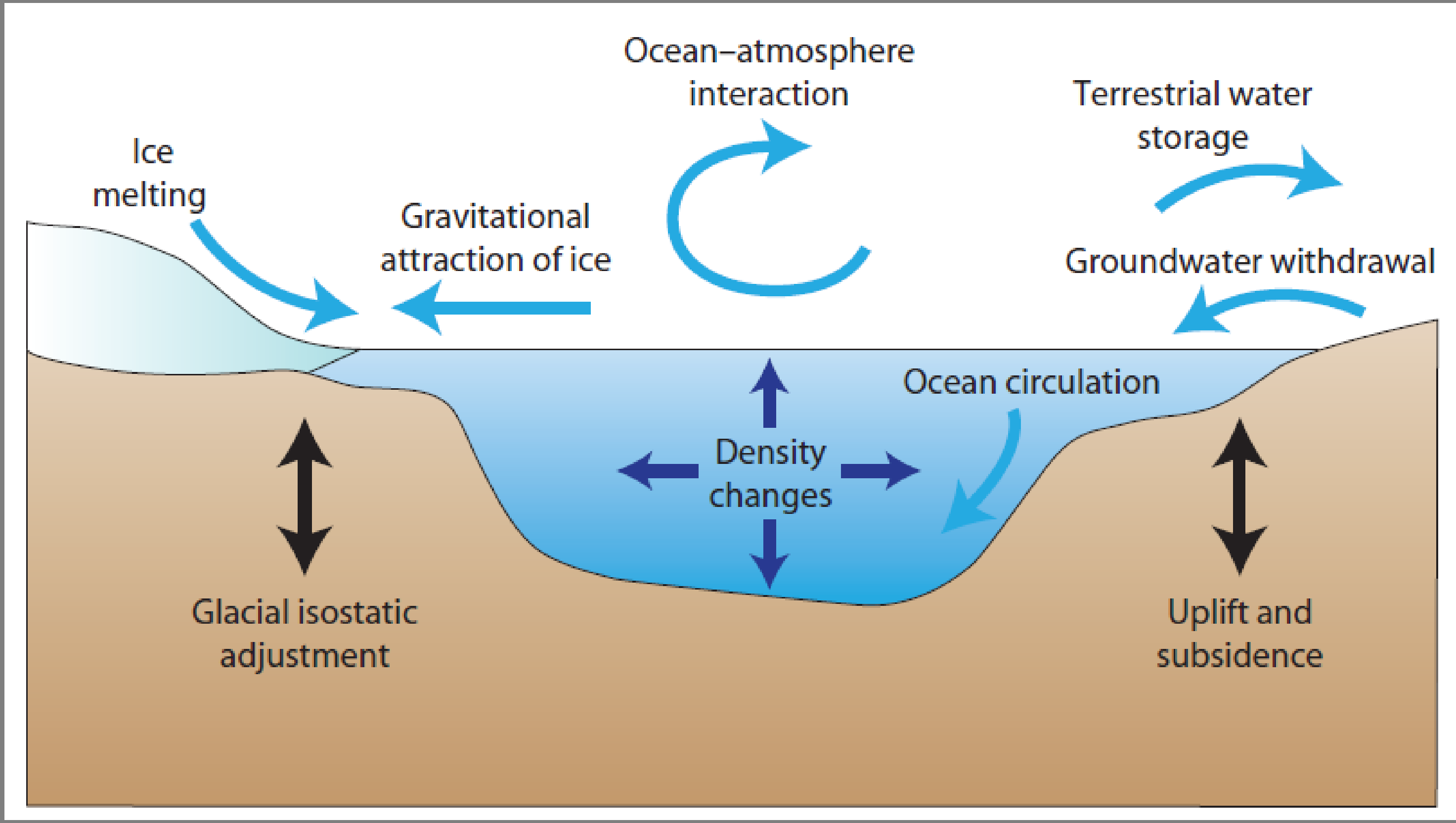
Tectonics

The ocean plate is descending below North America at the Cascadia Subduction Zone, causing local coastal areas to rise.

Ocean and North America plates are sliding past one another along the San Andreas Fault, causing no vertical motion.



Components of Global and Regional Sea-Level Rise



Sea level at a particular place can be higher or lower than the global mean due to regional effects

Catastrophic Coastal Storms

- Most coastal damage is caused by the confluence of large waves, storm surges, and high astronomical tides during a strong El Niño
  - Such an event in 1982-83 caused more than $200 M in damage to California

- Water levels during these events can exceed projections for 2100
  - Their additive effects are significant

Committee Projections for California, Oregon, and Washington

- Based on climate models and extrapolations of observed trends
- Account for regional variations in ocean density, sea-level fingerprint of land ice melt, and vertical land motion along the coast
- Projections made for two tectonic regions
  - North of Cape Mendocino, California (land is rising)
  - South of the cape (land is sinking)

Factors that Affect Sea-Level Rise Along the U.S. West Coast

Local sea level rises if the ocean rises and/or the land sinks

- Global sea-level rise
- Atmosphere-ocean circulation patterns in the Pacific (e.g., El Niño), which affect ocean levels
- Melting of modern and Ice Age glaciers and ice sheets, which affect ocean and land levels
- Tectonics and fluid withdrawal/recharge, which affect land levels

Uncertainties….

- Regional projections are more uncertain than global projections because there are more components.
- Uncertainties grow as the projection period lengthens:
  - Incomplete understanding of the climate system
  - Difficulty of modeling all components
  - Shortage of data at appropriate scales
  - Need for assumptions about future conditions
- Confidence in the projections:
  - High for 2030 and perhaps 2050
  - By 2100, we are confident only that the value will fall within the uncertainty bounds

Conclusions

- Sea-level in California (south of Cape Mendocino) is expected to rise nearly 1 m by 2100, about the same as global sea-level rise
- The projected rise is lower in Washington, Oregon, and California north of Cape Mendocino, about 60 cm, because the land is rising as seismic strain builds up
- Sea-level rise will magnify the adverse impact of storm surges and high waves on the coast.
- Wetlands mitigate some impacts, but will need high sedimentation, accommodation space, and/or uplift to survive after 2050.
- *A great earthquake (magnitude 8 or larger) along the Cascadia Subduction Zone would cause immediate subsidence and sea-level rise of an additional 1-2 m.*

Future Coastal Change

- Storms and sea-level rise are causing coastal cliffs, beaches, and dunes to retreat at rates from a few cm/yr to several m/yr

  Cliffs could retreat more than 30 m by 2100

- Wetlands protect inland areas by reducing flooding and wave height and energy

  Extent depends on vegetation, topography, and bathymetry

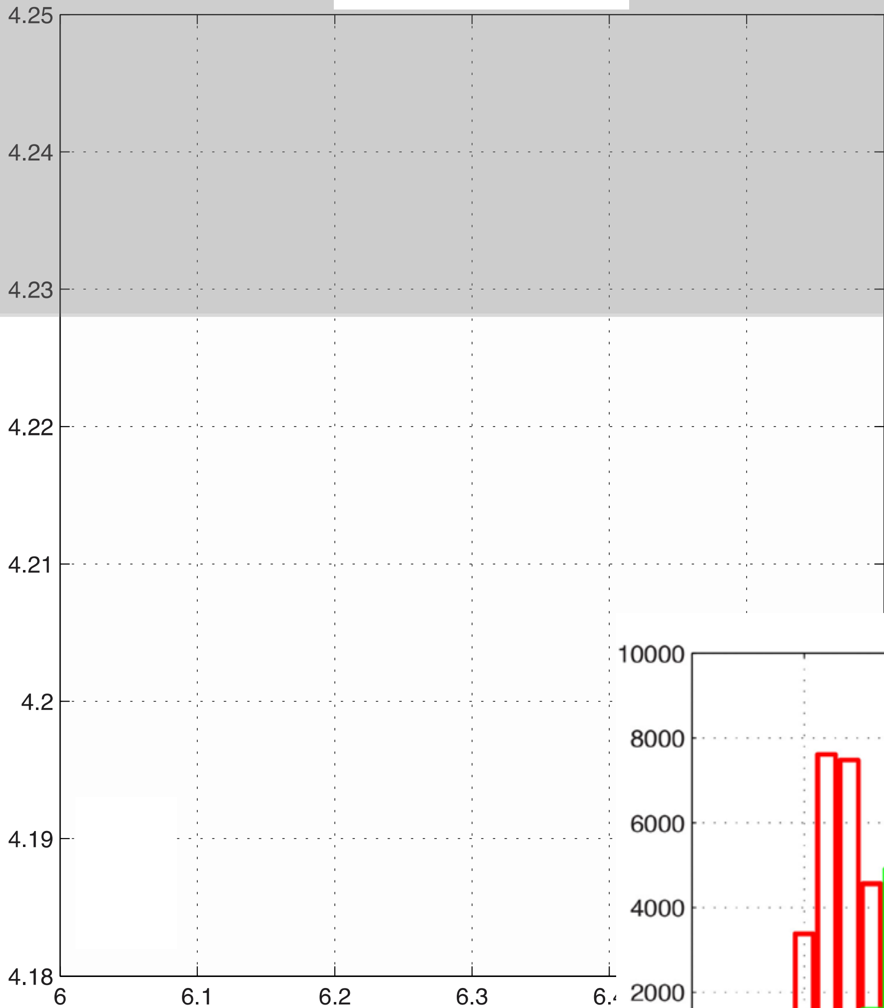
- Wetlands likely to keep pace with sea level until 2050

Survival to 2100 depends on maintaining elevation through high sedimentation, accomodation area, or uplift

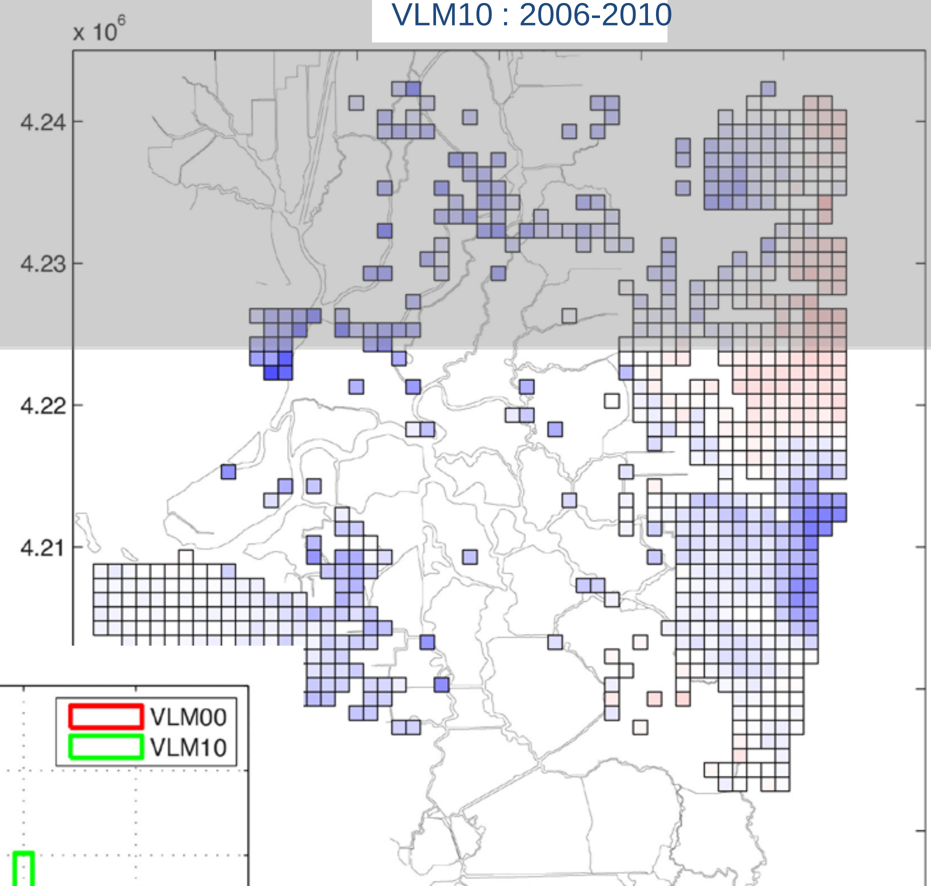
InSAR Vertical Displacement Rate Maps

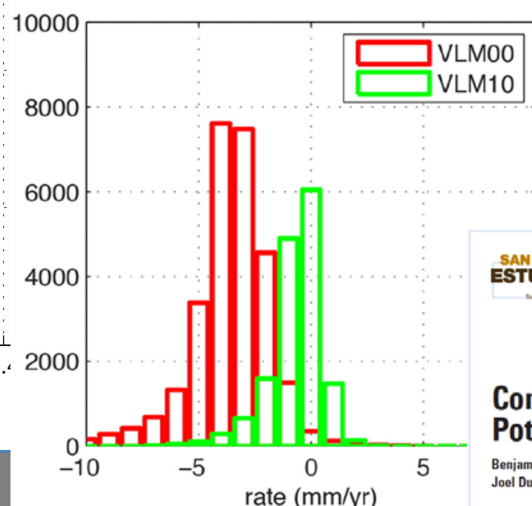
Land is sinking in Sacramento/San Joaquin Delta

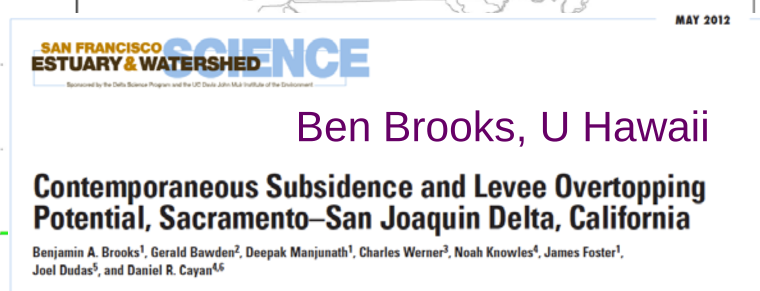
VLM00 : 1995-2000



VLM10 : 2006-2010





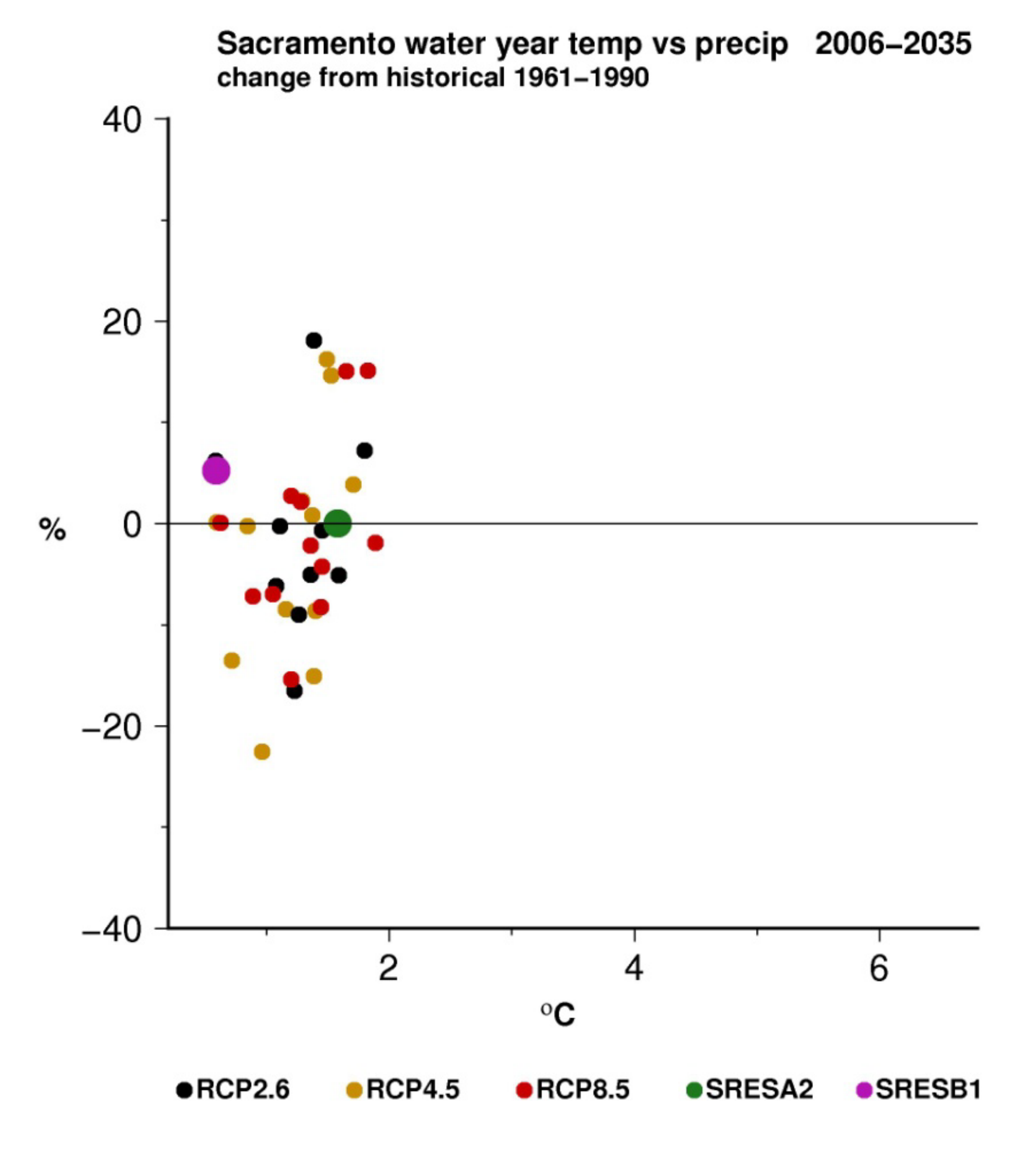

MAY 2012

SAN FRANCISCO ESTUARY & WATERSHED SCIENCE

Ben Brooks, U Hawaii

Contemporaneous Subsidence and Levee Overtopping Potential, Sacramento–San Joaquin Delta, California

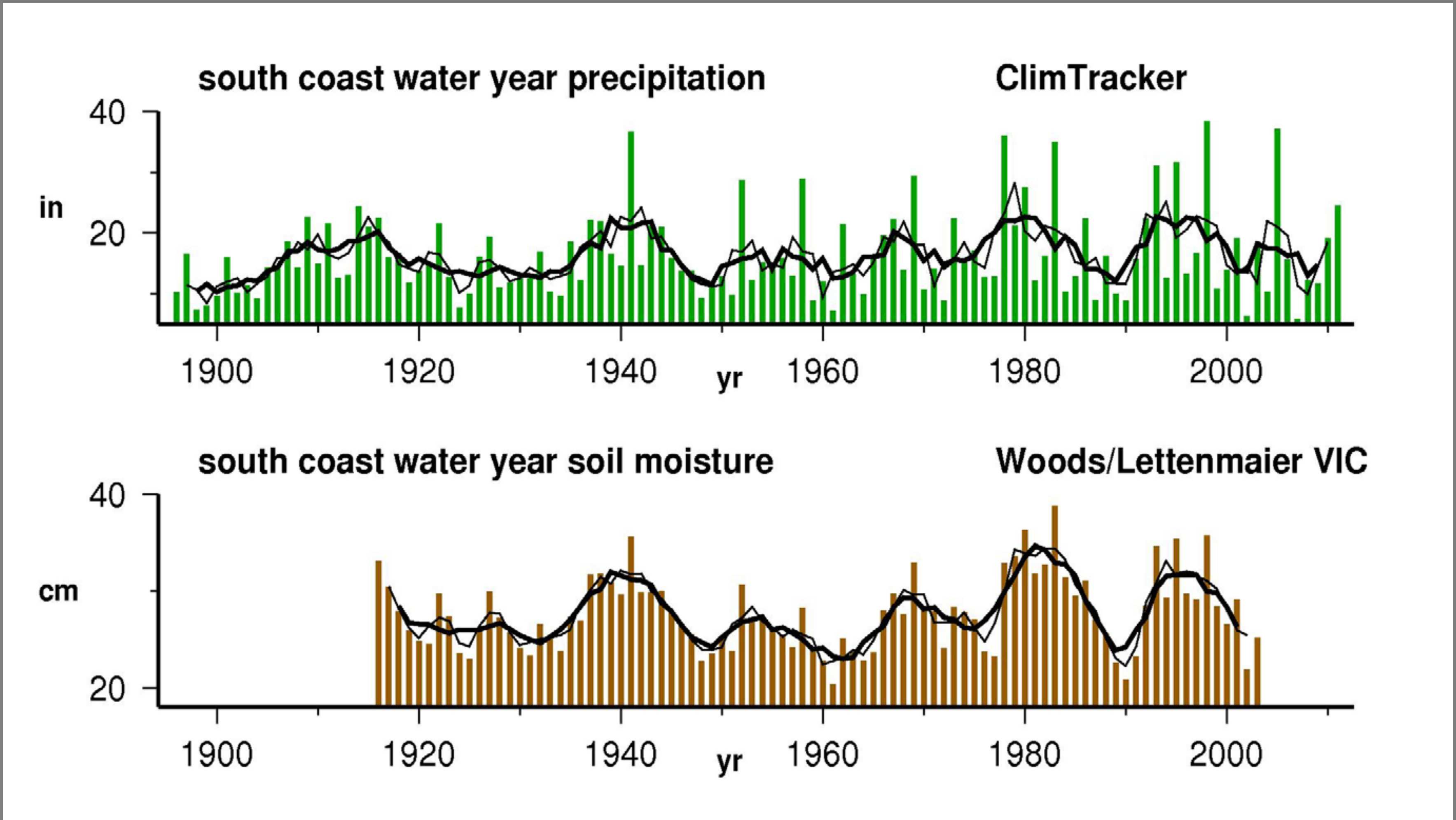
Benjamin A. Brooks[1], Gerald Bawden[2], Deepak Manjunath[1], Charles Werner[3], Noah Knowles[4], James Foster[1], Joel Dudas[5], and Daniel R. Cayan[4,6]



Sacramento water year temp vs precip 2006–2035
change from historical 1961–1990
40
20
0
–20
–40
%
2
4
6
°C
RCP2.6
RCP4.5
RCP8.5
SRESA2
SRESB1

CMIP5 model simulations

source	model	nlon	nlat
Beijing Climate Center	BCC-CSM1.1	128	64
Beijing Climate Center	BCC-CSM1.1(m)	320	160
Beijing Normal University	BNU-ESM	128	64
National Center for Atmospheric Research	CCSM4	288	192
Euro-Mediterranean Center on Climate Change; Italy	CMCC-CM	480	240
Euro-Mediterranean Center on Climate Change; Italy	CMCC-CMS	192	96
National Center for Meteorological Reseach; France	CNRM-CM5	256	128
Commonwealth Scientific and Industrial Research Organization; Australia	CSIRO-Mk3.6.0	192	96
Canadian Center for Climate Modelling and Analysis	CanESM2	128	64
European Center; Netherlands	EC-EARTH	320	160
Chinese Academy of Sciences	FGOALS-s2	128	108
Geophysical Fluid Dynamics Laboratory	GFDL-ESM2G	144	90
Geophysical Fluid Dynamics Laboratory	GFDL-ESM2M	144	90
Hadley Center Met Office	HadGEM2-CC	192	145
Institute of Numerical Mathematics; Russian Academy of Sciences	INM-CM4	180	120
Institut Pierre Simon Laplace	IPSL-CM5A-LR	96	96
Institut Pierre Simon Laplace	IPSL-CM5A-MR	144	143
Institut Pierre Simon Laplace	IPSL-CM5B-LR	96	96
Atmosphere and Ocean Research Institute; Tokyo	MIROC-ESM	128	64
Atmosphere and Ocean Research Institute; Tokyo	MIROC-ESM-CHEM	128	64
Atmosphere and Ocean Research Institute; Tokyo	MIROC5	256	128
Max Planck Institute for Meteorology	MPI-ESM-LR	192	96
Max Planck Institute for Meteorology	MPI-ESM-MR	192	96
Meteorological Research Insitute; Japan	MRI-CGCM3	320	160
Norwegian Climate Center	NorESM1-M	144	96



Great year-to-year variability of precipitation, San Diego

Ranges from ~33% to 280% of average

global climate models have been downscaled across California

limited number of climate measures

* having and sustaining local observational datasets is valuable

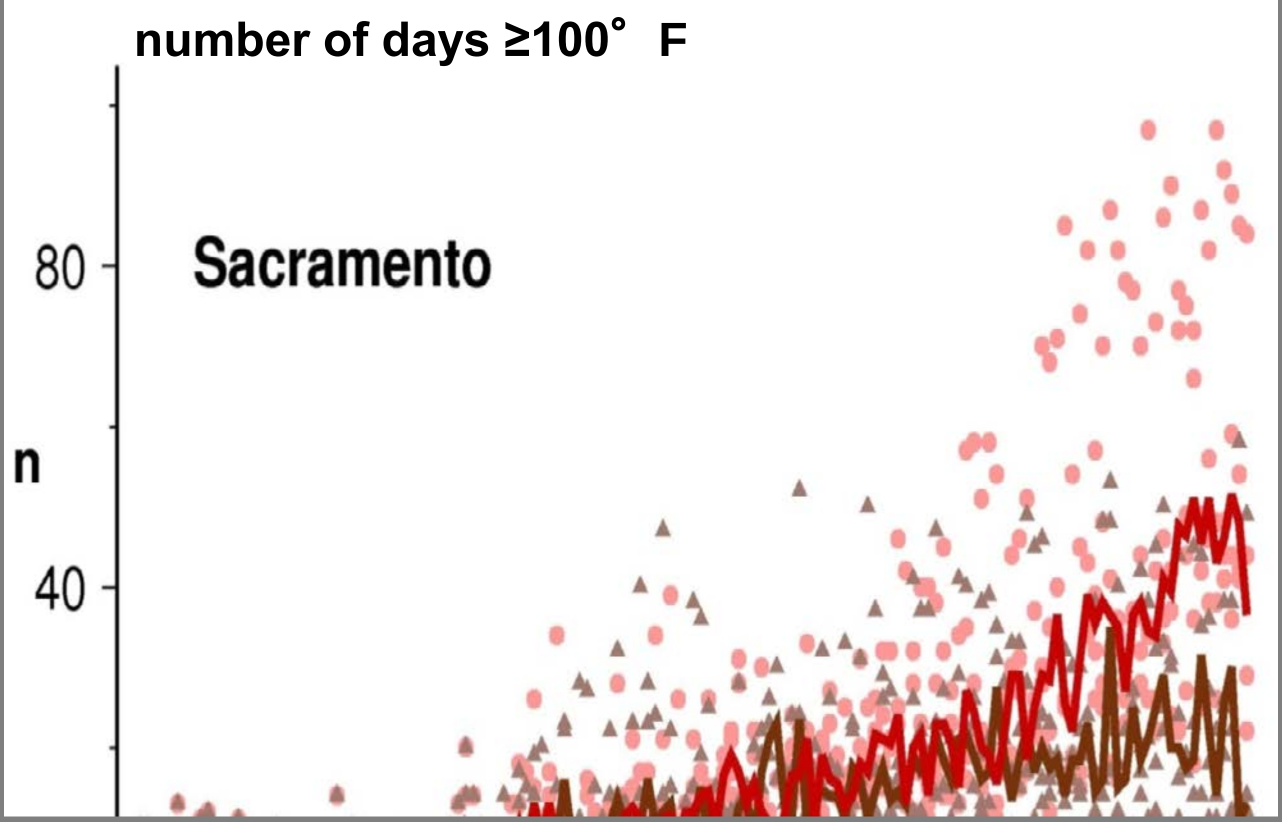
* understanding vulnerabilities is crucial

Heat Waves

Projected in Sacramento,

SRES A2 and SRES B1 GHG Emissions Scenarios

Number of Days (n), April–October, When Maximum Temperature (Tmax) Exceeds the 98th Percentile Historical (1961–1990) Level of 38ºC (100.4ºF) at Sacramento from Four BCCA Downscaled GCMs. Brown carrots and red dots shown for B1 and A2 emission scenarios, respectively. Thick brown (B1) and red (A2) lines show median value from the four simulations.



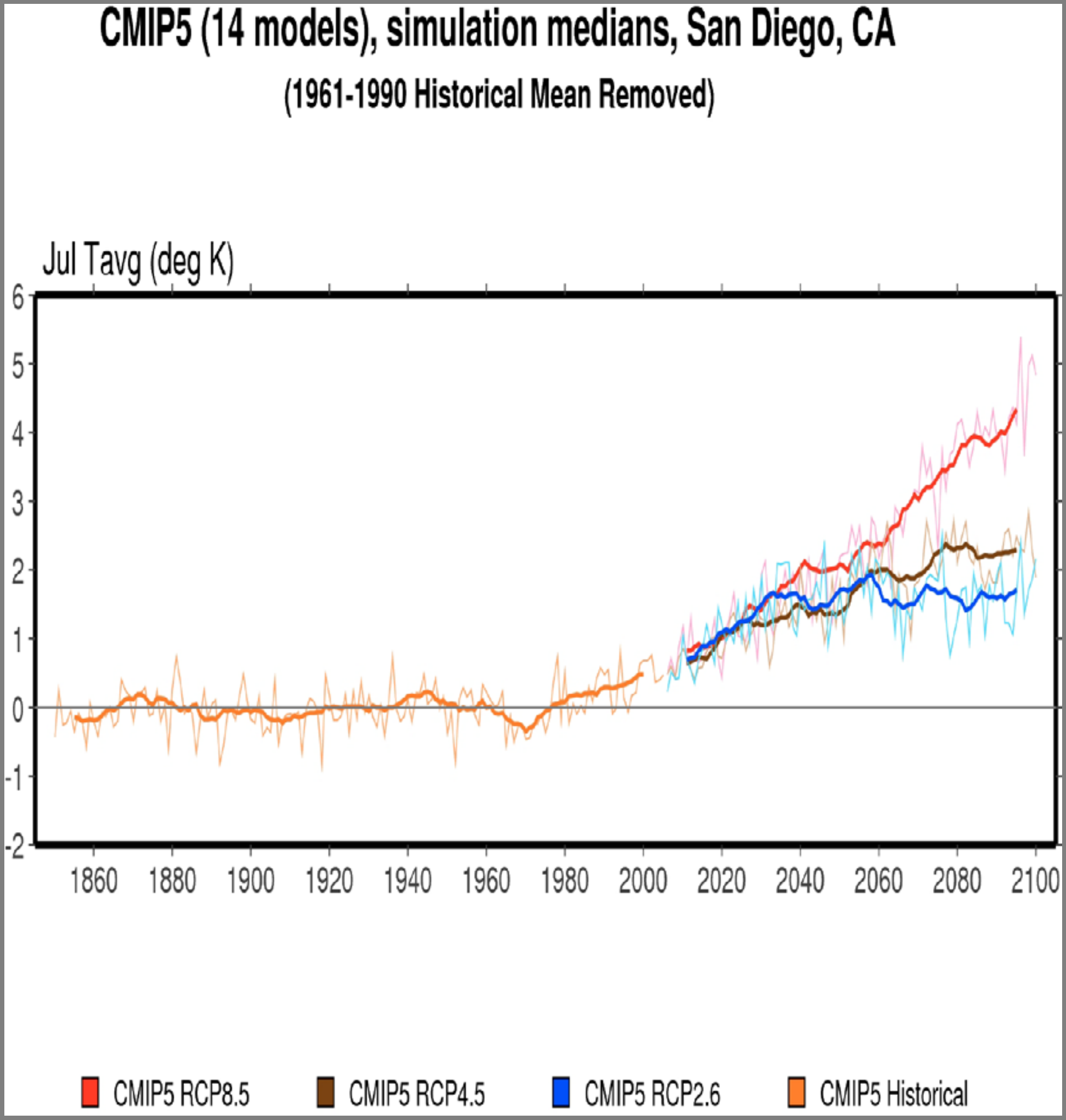
Median change

July Temperature

14 GCMs

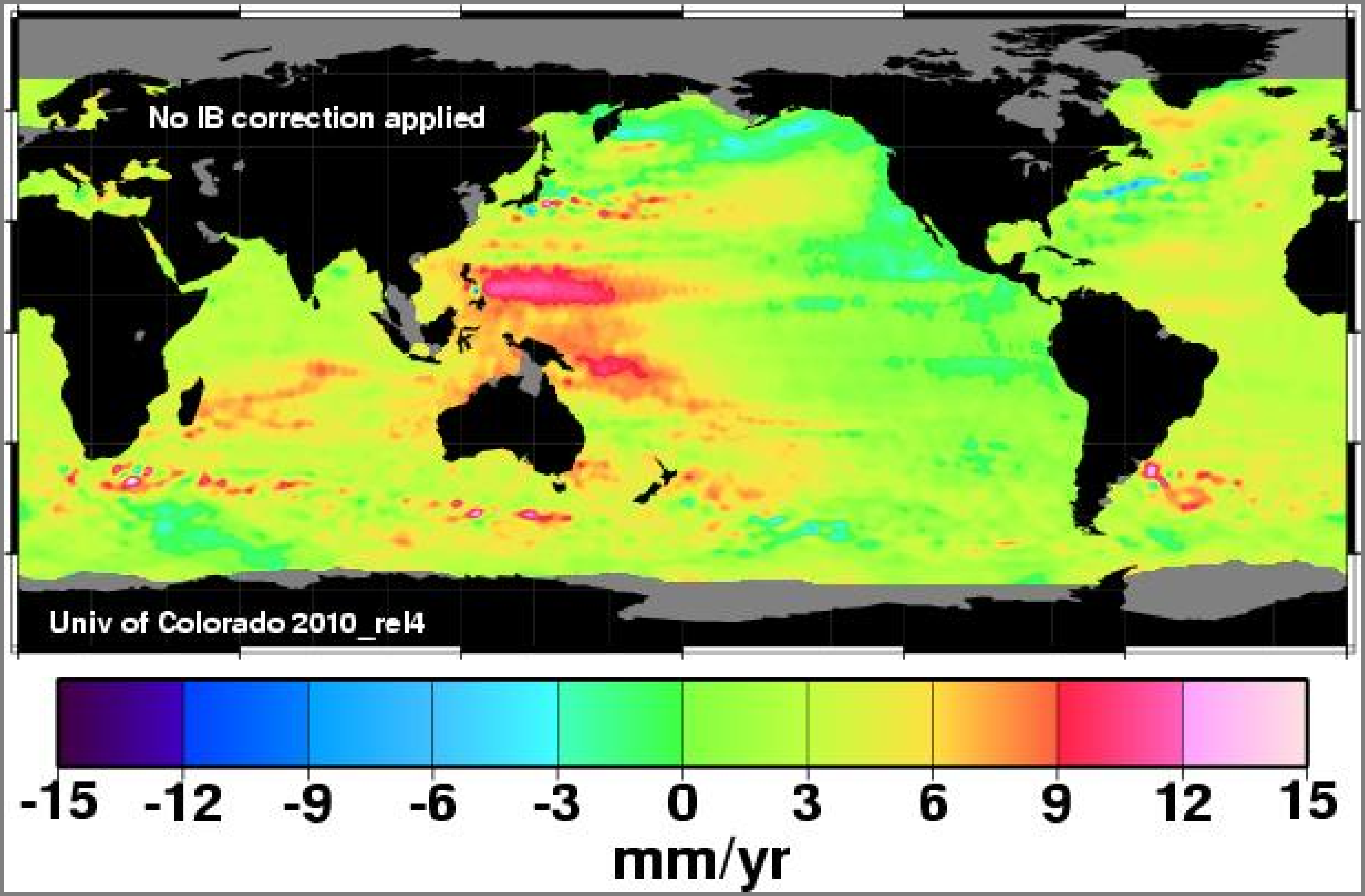
3 RCP emissions Scenarios

IPCC 5th Assessment (CMIP5) models



Sea Level Trends 1992-2010

How much/how fast will be future sea level rise along the California Coast?



Steve Nerem et al. U. Colorado